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LIFT ANALYSIS ON THE BOW SEAL OF THE SURFACE EFFECT SHIP TESTCR--ETC(U)
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Monterey, California

LEVEL II

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6 LIFT ANALYSIS ON THE BOW SEAL
OF THE SURFACE EFFECT SHIP TESTCRAFT XR-3

by

10 James R. Snider

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Thesis Advisor: D.M. Layton

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Lift Analysis On The Bow Seal Of The Surface Effect Ship Testcraft XR-3

by

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Captain, United States Army
B.S., Engineering, USMA, 1970

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

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September 1979

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ACKNOWLEDEMENT

The author gratefully acknowledges the assistance and support provided by Professor Donald M. Layton and Mr. Michael Odell. Without their patient guidance, this project would not have obtained the success that it did.

I. INTRODUCTION

A. BACKGROUND

In recent years the Air Cushioned Vehicle (ACV) has moved from the area of theoretical research to that of technical development resulting in several operational systems. The ACV may be defined as any self-propelled vehicle which is totally or partially supported above the surface on which it operates by a cushion of air. ACV's have been developed for overland operation, sea operation, or a combination of both.

Surface effect ships belong to the family of ACV's, and may be divided into two main classifications: Ground Effect Machines (GEM), which are frequently called "Hovercraft" (a trade name), and Captured Air Bubble (CAB) craft. The Hovercraft is supported entirely on an air cushion and is constantly pumping air under the lower edge of the vehicle's flexible, air-retaining "skirt". Because the entire vehicle is completely supported several inches above the surface by the air cushion, the hovercraft is a true amphibian. The CAB, which does not have this amphibious capability, has the advantage of requiring a greatly reduced air flow volume because of the captured effect of the air. This results in a reduction of the power required to pump the lifting air, particularly at higher vehicle weights.

B. SURFACE EFFECT SHIPS

Because the CAB is restrcited to waterborne operation, the term Surface Effect Ship (SES) is in general use for the Captured Air Bubble vehicle. All references to Surface Effect Ship in this report are considered to signify an air cushion vehicle of the Captured Air Bubble type.

The SES rides across the water on a captured cushion of mechanically pressurized air. The craft employs air constraining skirts which extend from the vehicle to below the surface of the water at the bow and stern. The solid sidewalls and the skirts contact the water forming a plenum beneath the craft into which air is ducted from fans. When a large volume of air is pumped into this space an atmospheric overpressure is produced which causes the craft to rise on a "bubble" of air. Because only a small amount of air escapes the plenum (usually under the rear seal during the craft's forward motion), only a relatively small amount of air must be replaced to maintain the supporting captured air bubble. The large, useful surface of the SES upper deck, the relatively low power required for lift, and the low hydrodynamic drag of the small underwater body combine to produce a high speed vessel with a large payload capacity.

The SES is not propelled by the air from the lift engines, but must be fitted with separate propulsion and steering systems. Propulsion systems may be the standard submerged propeller, high speed water jets, semi-submerged cavitating propellers, or deck mounted fans. Steering systems in use are conventional rudders, variable thrust angles (for water jets),

or differential thrust applied to multiple propulsion units.

C. THE XR-3

The XR-3 was constructed in 1965 by the David Taylor Model Basin (now the David W. Taylor Naval Ship Research and Development Center). The craft was shipped to the Aerojet-General Corporation for further testing and evaluation under the instructions of the Surface Effect Ship Project Office (SESPO). Aerojet General Corporation operated the XR-3 testcraft in San Diego Bay for 108 hours of waterborne operation between April and November of 1968.

In March 1970, the XR-3 was transferred to the Naval Postgraduate School for the purpose of investigating several areas of interest in the field of basic and advanced surface effect ship technology in accordance with a SESPO statement of work. While at the Naval Postgraduate School the XR-3 has been used extensively for SES research.

The XR-3, Figures 1 and 2, is twenty-four feet long, twelve feet wide and weighs 6090 lbs. in a loaded condition. The craft is propelled and steered by two fifty-five horsepower Chrysler outboard engines. The plenum pressure is maintained by five single-cylinder air-cooled internal combustion engines. Figures 3 shows the XR-3 plenum area. Electrical power is provided by a 1500 watt, 110 volt auxiliary power unit.

D. THESIS OBJECTIVE

To optimize the design of future surface effect ships, it is necessary to investigate the aerostatic and hydrodynamic forces which act on the craft during actual operation. To

gain a useful data base these forces must be measured during the various situations and maneuvers conducted by the SES. This report investigates the lift forces that are experienced by the bow seal during testcraft maneuvers at various turning rates and at varying center of gravity (C.G.) locations.

II. NATURE OF THE PROBLEM

A. DRAG VS. VELOCITY CURVE

An excellent method of visualizing the forces on the seals of the XR-3 is to examine the craft as it accelerates from a stationary position to a "cruise" velocity.

Figure 4, Reference 1, shows a typical drag versus velocity curve for the XR-3. The craft pushes two waves as it accelerates forward, one at the bow and one at the stern. Point 1 is the velocity at which the craft rides over the stern wave. After this point, called the Secondary Hump, there is a sharp reduction in drag. Figure 5 shows the XR-3 at a velocity just below Point 1.

The slope of the drag curve between points 1 and 2 of Figure 4 is negative, and only unstable equilibrium can be achieved. Therefore, the craft can rarely operate in this region.

The craft accelerates against the resistance of the bow wave ahead of the bow seal until the craft overrides this wave. This region is between points 2 and 3 in Figure 4. Point 3 is called Primary Hump or Hump. Figure 6 shows the XR-3 operating at a velocity between Secondary and Primary Hump. It can be seen that the craft has only a bow wave in this velocity range.

After the craft has passed Hump velocity there is neither a bow or stern wave and the drag is primarily a function of hydrodynamic resistance.

Figures 7 and 8 show the XR-3 "on the cushion", past Hump velocity. All lift measurements for this investigation were made in this region.

B. SEAL FORCES

The forces on the bow and stern seals are a result of aerostatic pressure and hydrodynamic action. The aerostatic pressure comes from the plenum pressure acting on the rear of the bow seal and on the face of the rear seal. Air is continuously pumped into the plenum from the lift fans and is vented under the seals or sidewalls. This flow of air creates a pressure contour within the plenum. The plenum pressure acts to force the bow seal down into the water, and hydrodynamic forces act to lift the bow seal while at the same time imparting an aft drag force.

Measurement of the aerostatic lift and drag forces on the rear seal is complicated by the seal's lack of rigidity. This allows the seal to distort from wave action and from the pressure distribution on the seal face. However, the ability of the bow seal to distort is desirable considering the craft's motion in rough water, Ref. 2. Wave energy is absorbed by the flexible seal rather than creating a lifting force to increase craft heave.

III. DESCRIPTION OF EQUIPMENT

A. THE BOW SEAL

The flexible bow seal, Figure 9, is attached to a rectangural, aluminum angle framework. This framework is attached to the wet deck between two sidewall hulls by four lift sensing devices. There are two drag sensing load cells attached to the framework in the same plane as the frame which transmit forward and aft drag data for the seal. The seal bag is a rubberized fabric which is stiffened by twelve equally spaced steel spring stays. The stays impart some stiffness to the seal, and they assist in maintaining seal shape. The seal bag consists of two compartments separated by a center membrane which has several large holes to allow air to flow freely between the two sections of the seal. Pressurized air is ducted into the region of the framework allowing full inflation of the seal.

To attach the lift cells to the craft, 1/2-inch aluminum plates were attached to existing hull strength members. The load cells had 1/2-inch by 13-inch TPI threaded rods attached to each end, one end of which was screwed into attachment points on the seal and the other attached to a 1/2-inch aluminum plate. Figure 10 shows a lift load cell as seen from the weather deck with the access plate removed.

B. LIFT LOAD CELL ELECTRONICS

The lift load cells receive power from and send signals

to an electronics package designed for the XR-3 project by Michael Odell. Power is received from the craft's 12 volt system and is reduced to five volts by a 7805 LM340L electronic voltage regulator. The output of the load cells is a ± 5 VDC analog signal which is amplified by a pair of operational amplifiers. Separate lift force summation circuits are provided to properly add the amplified cell outputs if desired. The resultant load cell analog signals representing individual or total lift are recorded on separate channels of the onboard data recorder, a Pemco fourteen channel magnetic tape recorder (Model 120B). The instrumentation circuit is equipped to provide zero or neutral readings and signal inversion where necessary to adhere to the reference measurement system.

C. DATA ACQUISITION AND REDUCTION SYSTEM

The following sensors are installed as a basic part of the XR-3 Data Acquisition System shown in Figure 11:

1. Port Thrust
2. Starboard Thrust
3. Forward Seal Pressures
4. Aft Seal Pressure
5. Plenum Pressure
6. Testcraft Velocity
7. Water Immersion Height
8. Pitch Angle
9. Roll Angle
10. Yaw Angle

11. Pitch Rate

12. Roll Rate

13. Yaw Rate

14. Lateral Acceleration

15. Vertical Acceleration

16. Longitudinal Acceleration

17. Rudder Position

The Data Reduction System, Figure 12, consists of a signal conditioning unit, a two channel strip chart recorder, analog to digital converter, programmable calculator with storage, and a digital X-Y recorder.

The signal conditioning unit receives all 14 channels from the tape recorder and through use of a patching matrix provides up to nine output channels through signal conditioning amplifiers. Additional information about the data reductions system may be found in Refs. 1 and 3.

IV. EXPERIMENTAL PROCEDURE

A. CENTER OF GRAVITY

Liens, Ref. 4, describes in detail the method used for determining the initial weight and balance data for the XR-3. Included in this reference are the details concerning the initial determination of the optimum center of gravity location, and the methods used to vary the center of gravity. Because a constant throttle setting was required during this experimentation, the human ballast technique was used to change the C.G. location.

B. PROCEDURE

The voice edge track of the tape was annotated with necessary information, and the equipment was calibrated prior to each day's run. The calibration signals provided by the lift and drag circuitry were zeros and 200 millivolts (200 pounds) on all circuits.

A base condition was established with a testcraft weight of 6090 pounds at a center of gravity 117.3 inches forward of the aft transom. The test condition represented the craft loaded with a full fuel load with the pilot and test coordinator seated in the cockpits.

Power was applied in small increments until Hump velocity was passed at about 10 knots. The craft was accelerated to 20 knots. This power setting was held while the testcraft was piloted in a path resembling the Spiral of Archimedes.

Beginning with the testcraft in a straight, constant velocity condition, a slight turn in one direction was started for a brief period. The turn rate was increased in small increments until the maximum turn rate was reached. These runs were conducted for both left and right turning spirals.

The Center of Gravity was changed using the procedure outlined in Ref. 4. A forward center of gravity was established at 119.6 inches from the transom, and an aft C.G. at 113.5 inches. The Spiral of Archimedes maneuver was repeated for both C.G. locations. It was necessary to repeat certain conditions and tests when the data, that was observed while being recorded, appeared to deviate from expected values, or when encountering surface turbulence such as waves or boat wakes.

Data Reduction was done by obtaining stripchart traces of the day's runs and reading the values by hand with mental averaging of signal noise. This method proved satisfactory since runs made for the same conditions, taken on different days yielded repeatable data. All data was hand plotted. Although the general weather conditions were not significant in the testing, the amount of wind and wake generated was a determining factor in the quality of data recorded.

V. RESULTS AND CONCLUSIONS

The data obtained during the experimentation is presented in Tables 1 through 3. Graphical representation of the data is presented in Figures 16 through 26.

The forces acting on the bow seal are complex, and many are dependent upon the shape of the seal and the amount of seal which is immersed during various operating conditions. These quantities were not measured during this experimentation. Instead, the lift forces were isolated and measured as they were transmitted from the seal to the hull of the XR-3. The net lift force on the bow seal is caused primarily by the displacement of water by the seal. Other contributions to the lift force are due to the flow of water beneath the bow seal and the planing action of the seal as the craft moves forward, Ref. 5. Bow seal lift varies directly with wave action, and therefore calm water is essential in reducing scatter.

Figure 13 shows that lift remains nearly constant as velocity varies past hump. Because all experimental runs were conducted at speeds above hump, changes in lift were primarily due to the changes in center of gravity location and to changes in rate of turn.

Figure 14 shows the bow seal and the attached lift and drag load cells. It should be noted that lift cells 2 and 4 are mounted on the right of the seal and lift cells 1 and 3 are mounted on the left side of the seal. Figure 15 is a

typical stripchart section from the data reduction unit showing the variation of lift with turn rate. Because of the sensitivity of the lift load cells it is extremely difficult to determine continuous data points. A more meaningful use of the stripchart in lift analysis was to note trends, and to use key data points to help visualize these trends. This method was used in presenting the data in graphical form shown in Figures 16 through 26. Data for these graphs was obtained during various water conditions which caused some unexpected inconsistencies in data. These were minor, however, and did not hinder the test results.

Figures 16 through 26 clearly show that with increasing turn rate lift increases on the side of the bow seal in the direction of the turn, and lift decreases on the side opposite the direction of turn. For example, Figures 16 and 18 represent the testcraft in an increasing right turn with the C.G. located at the optimum or "mid" C.G. location. Figure 16 shows the results of the sum of Lift 2 and Lift 4, or the lift on the right side of the bow seal, and Figure 17 shows the results of the sum of Lift 1 and Lift 3, or the lift on the seal's left side (Refer to Figure 14). Figure 16 clearly shows an increase in Lift 2 and Lift 4 as the turn rate is increased, and Figure 18 shows a decrease in Lift 1 and Lift 3. In both cases the change in lift varies most dramatically at lower turn rates, then levels off near maximum rate of turn. This increase in lift on the side of the seal in the direction of the turn is due to increased water force encountered in the turn. The slope of Figure 18 is steeper than that of

Figure 15 indicating that lift changes more rapidly on the side of the seal away from the turn than on the side into the turn. This is probably due to the combination of a loss of water force on that side plus the additional loss of lift due to venting of plenum air along the testcraft's sidewalls. This result can clearly be seen again in Figure 17 and 19 which show a left turn with the same (mid) C.G. location.

The results observed in turns with the mid C.G. location were repeated in the aft and forward C.G. locations. Figures 20 through 23 (Forward C.G.), and Figures 24 through 26 (Aft C.G.), show the same general rule - that lift increases on the seal side in the direction of the turn and decreases on the side opposite the turn. The figures also reveal that the Center of Gravity location has a pronounced effect on the variation of lift with increasing rates of turn. Figure 20 shows that with a forward center of gravity the lift forces in the direction of the turn increase slowly with low rates of turn and then increase more rapidly at higher turn rates. The same result can be seen in Figure 22. This is probably due to the large increase in bow seal immersion depth due to the forward C.G. location. Figure 24 shows this same turn condition, (i.e. lift forces being measured in the direction of the turn), but with an aft C.G. location. In contrast to the former curves, the latter has a steep slope at low turn rates, and at higher turn rates the slope decreases. Figure 24 and 26 demonstrate the great effect that venting has on loss of lift. Both figures show the lift variation on the seal side opposite the direction of turn and with the center

of gravity aft. The lift drops off gradually as the turn is initiated and then decreases rapidly as the increased turn rate allows venting from the plenum.

Alfieri (Ref. 5) showed that as the C.G. is moved aft there is less lift generated by the bow seal. This series of experiments verified those results for the bow seal under conditions of varying turn rates. In addition the results indicated a consistent pattern of lift variation with increasing turn rate.

TABLE I

Condition 1 - XR-3 Weight 6180 lbs MID C.G.

RIGHT TURN

TURN RATE (DEG/SEC)	$L_2 + L_4$ (lbs)	TURN RATE (DEG/SEC)	$L_1 + L_3$ (lbs)
1.01	280	3.33	277
2.54	283	6.0	273
3.1	287	6.67	265
3.77	285	10.0	255
4.0	285		
7.5	295		
8.8	295		
9.1	293		

LEFT TURN

TURN RATE (DEG/SEC)	$L_2 + L_4$ (lbs)	TURN RATE (DEG/SEC)	$L_1 + L_3$ (lbs)
1.15	277	2.33	278
2.33	275	3.2	283
5.33	265	5.33	280
6.67	260	6.44	280
7.75	256	6.67	283
8.9	252	9.0	285

TABLE II

Condition 2 - XR-3 Weight (6810 lbs) Forward C.G.

RIGHT TURN

TURN RATE (DEG/SEC)	$L_2 + L_4$ (lbs)	TURN RATE (DEG/SEC)	$L_1 + L_3$ (lbs)
3.11	280	3.11	269
6.0	282	5.33	261
8.9	289	6.0	261
10.0	287	9.33	255
11.67	295	11.5	253
12.0	300		
13.0	305		

LEFT TURN

TURN RATE (DEG/SEC)	$L_2 + L_4$ (lbs)	TURN RATE (DEG/SEC)	$L_1 + L_3$ (lbs)
2.87	305	3.33	260
3.4	303	4.0	262
4.0	299	4.44	265
4.9	294	5.0	263
5.77	285	5.77	272
6.67	280	6.67	280
7.33	280	7.33	290
8.2	277		
9.0	274		

TABLE III

Condition 3 XR-3 Weight (6810 lbs) Aft C.G.

RIGHT TURN

TURN RATE (DEG/SEC)	$L_2 + L_4$ (lbs)	TURN RATE (DEG/SEC)	$L_1 + L_3$ (lbs)
3.11	265	3.11	252
3.33	272	3.33	250
5.0	275	5.0	250
6.44	280	6.44	242
8.67	283	8.667	223
13.33	288	10.55	220

LEFT TURN

TURN RATE (DEG/SEC)	$L_2 + L_4$ (lbs)
1.15	285
2.33	280
3.33	270
4.22	265
5.5	260

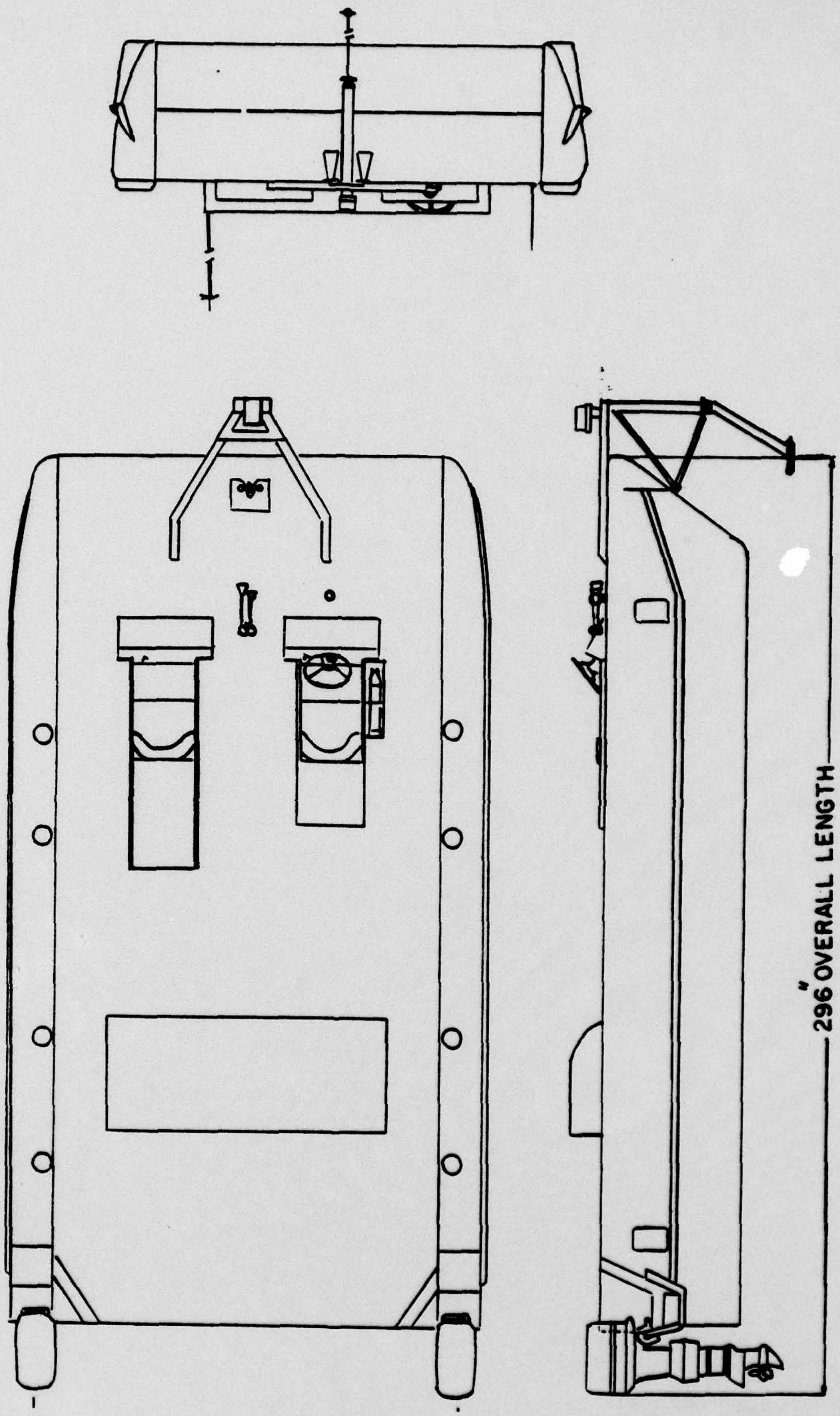

Figure 1. GENERAL CONFIGURATION OF THE XR-3

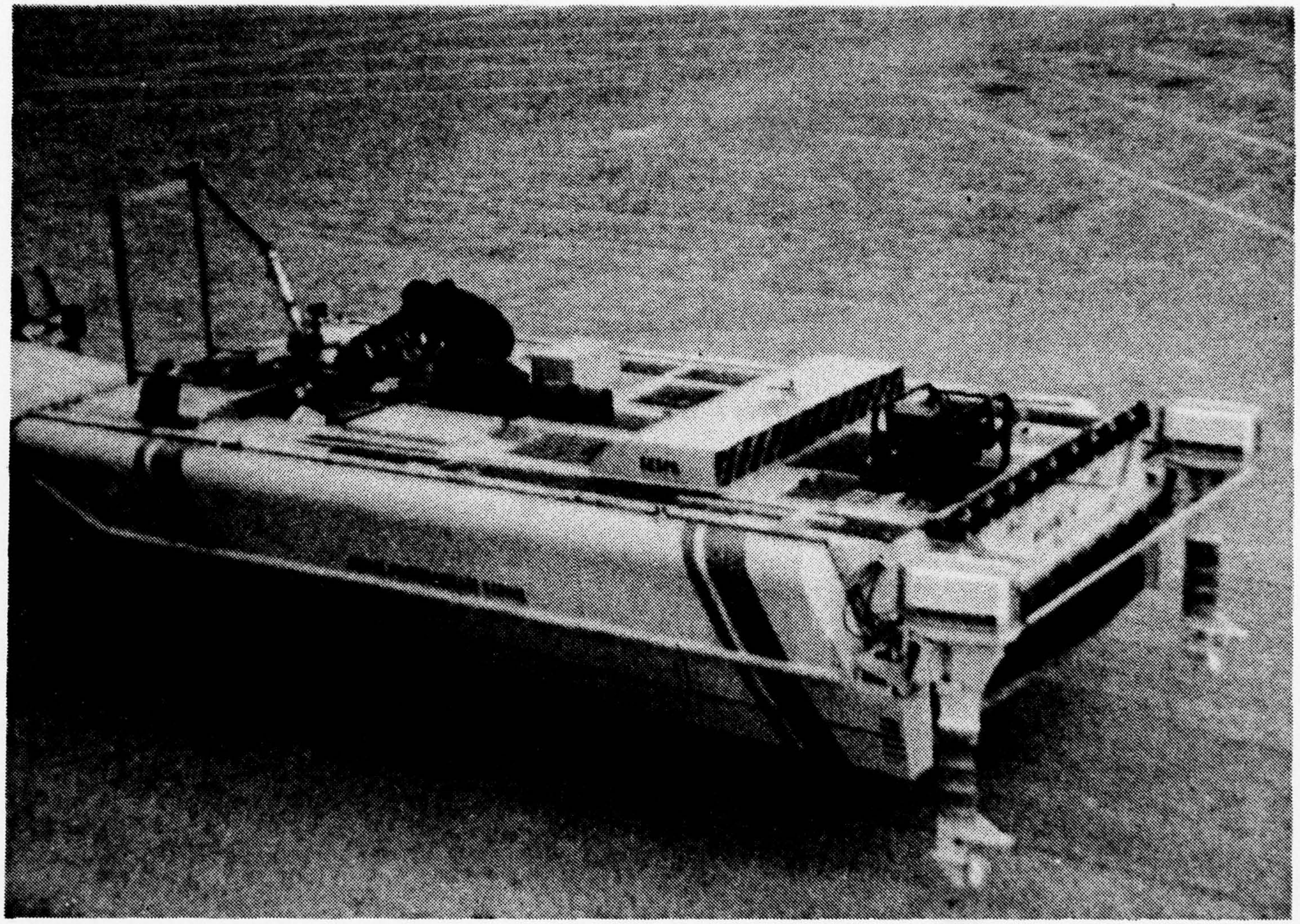

Figure 2. XR-3 VIEW FROM ABOVE

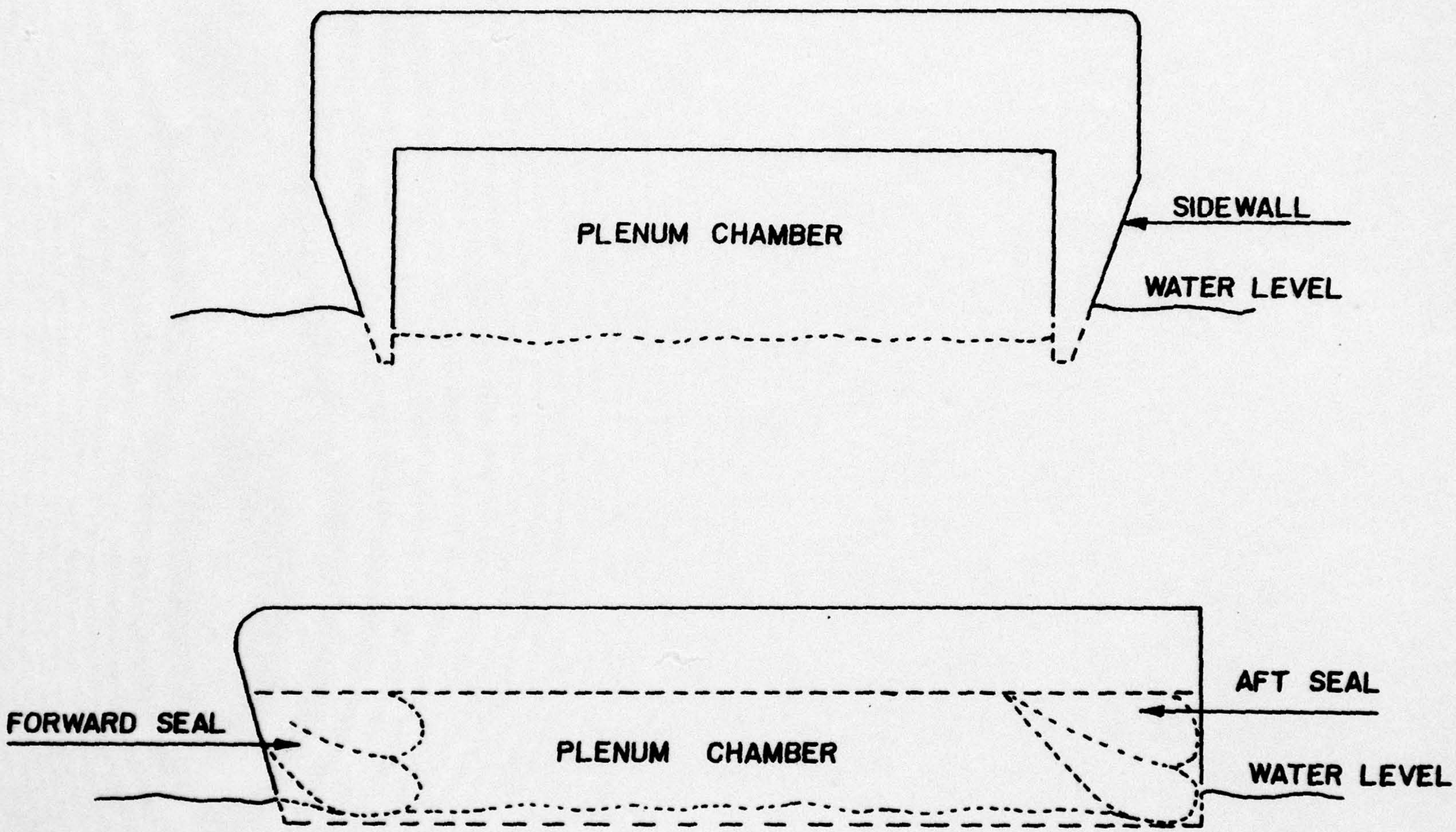

Figure 3. PLENUM CHAMBER AND SEAL OUTLINES

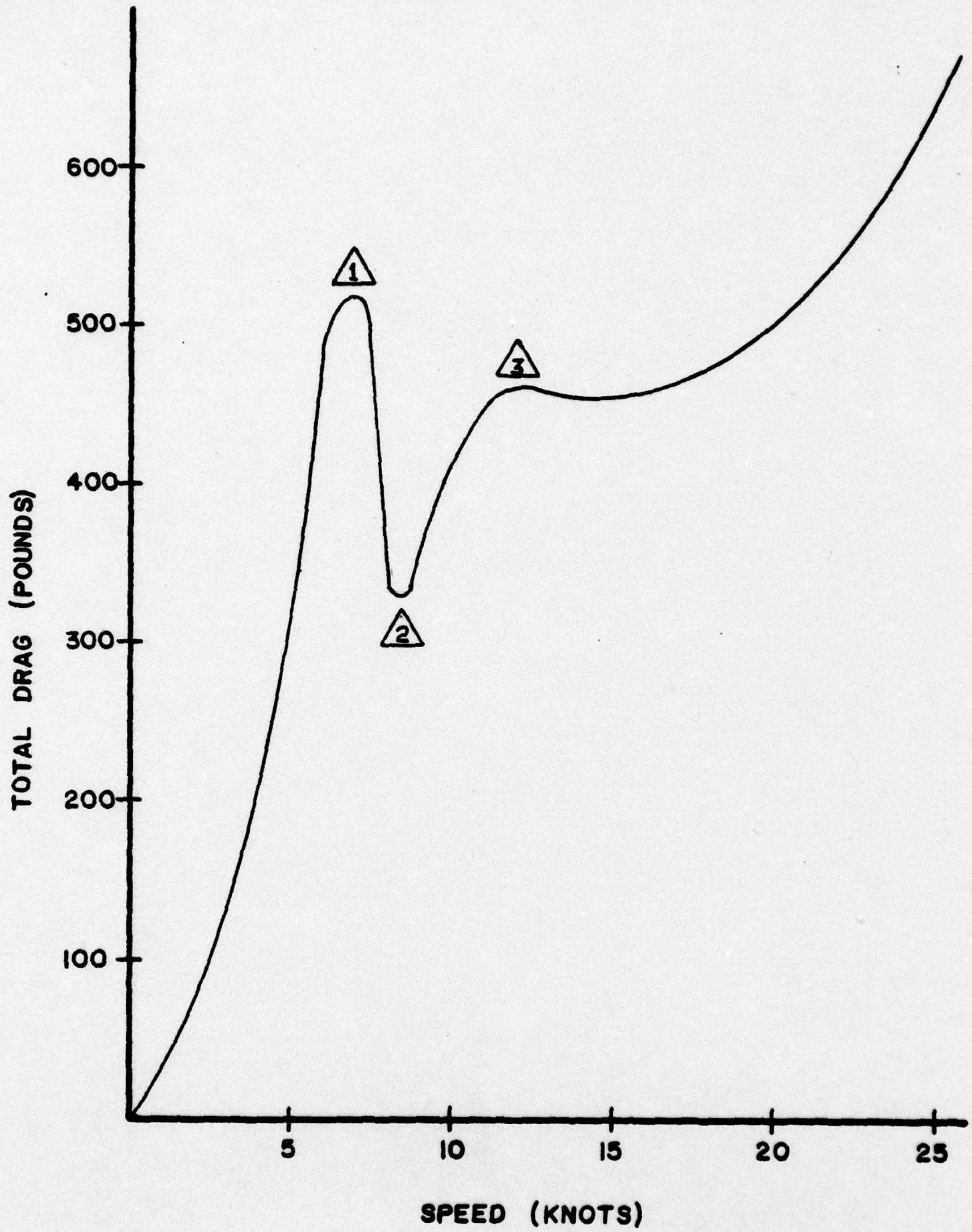

Figure 4. DRAG VS. VELOCITY (TYPICAL)

Figure 5. XR-3 BELOW SECONDARY HUMP

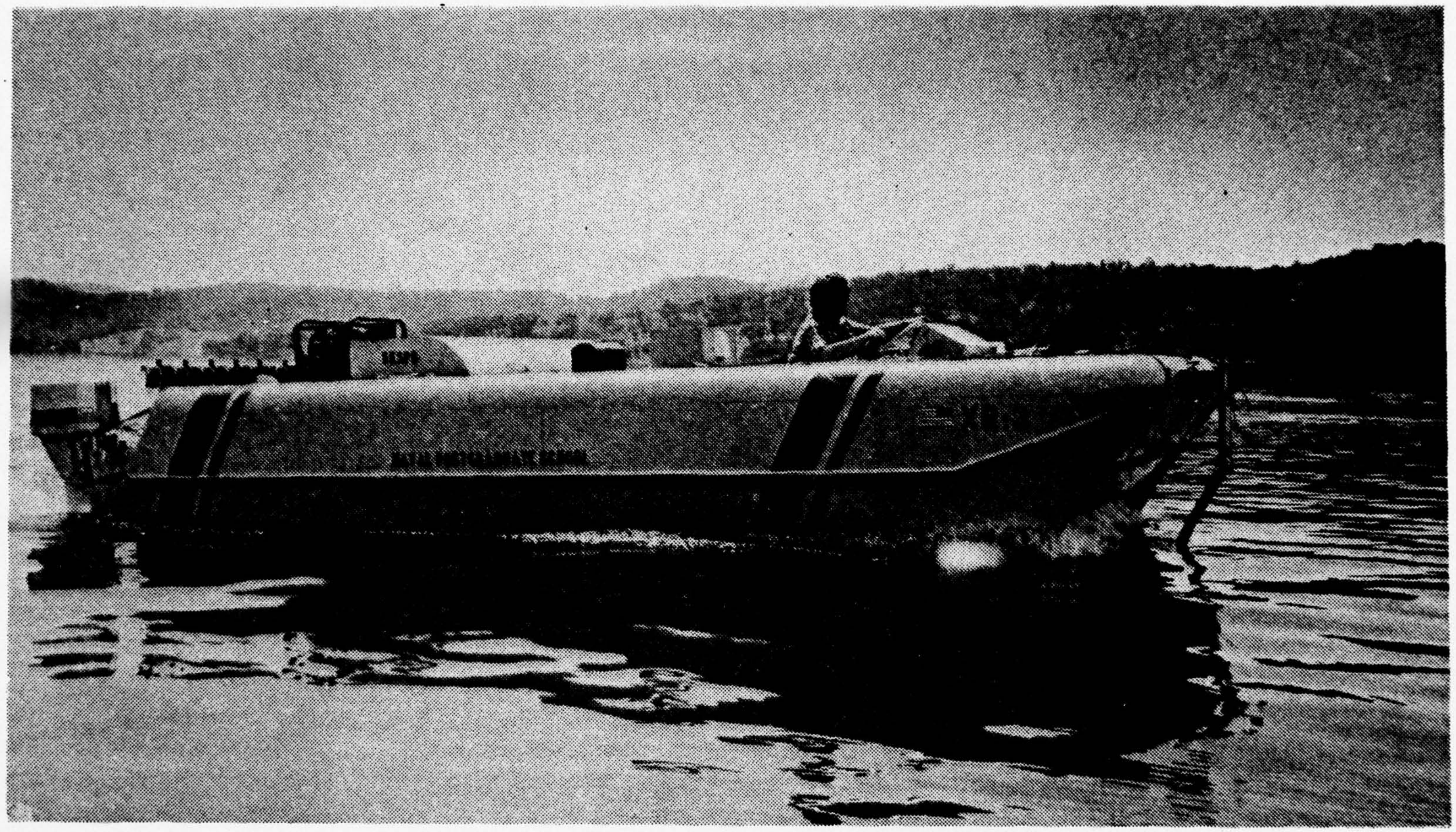

Figure 6. XR-3 BETWEEN SECONDARY AND PRIMARY HUMP

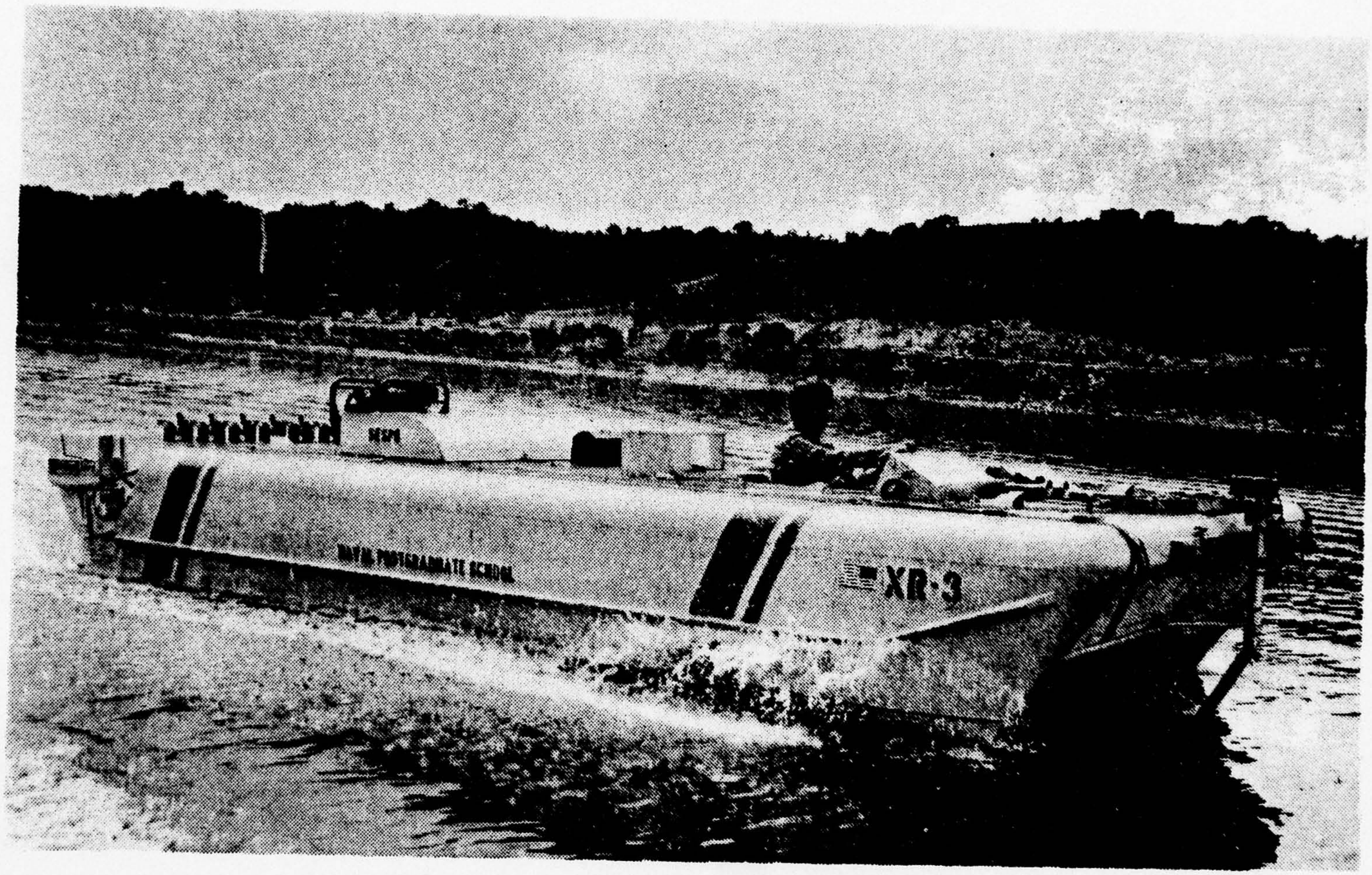

Figure 7. XR-3 POST HUMP BOW VIEW

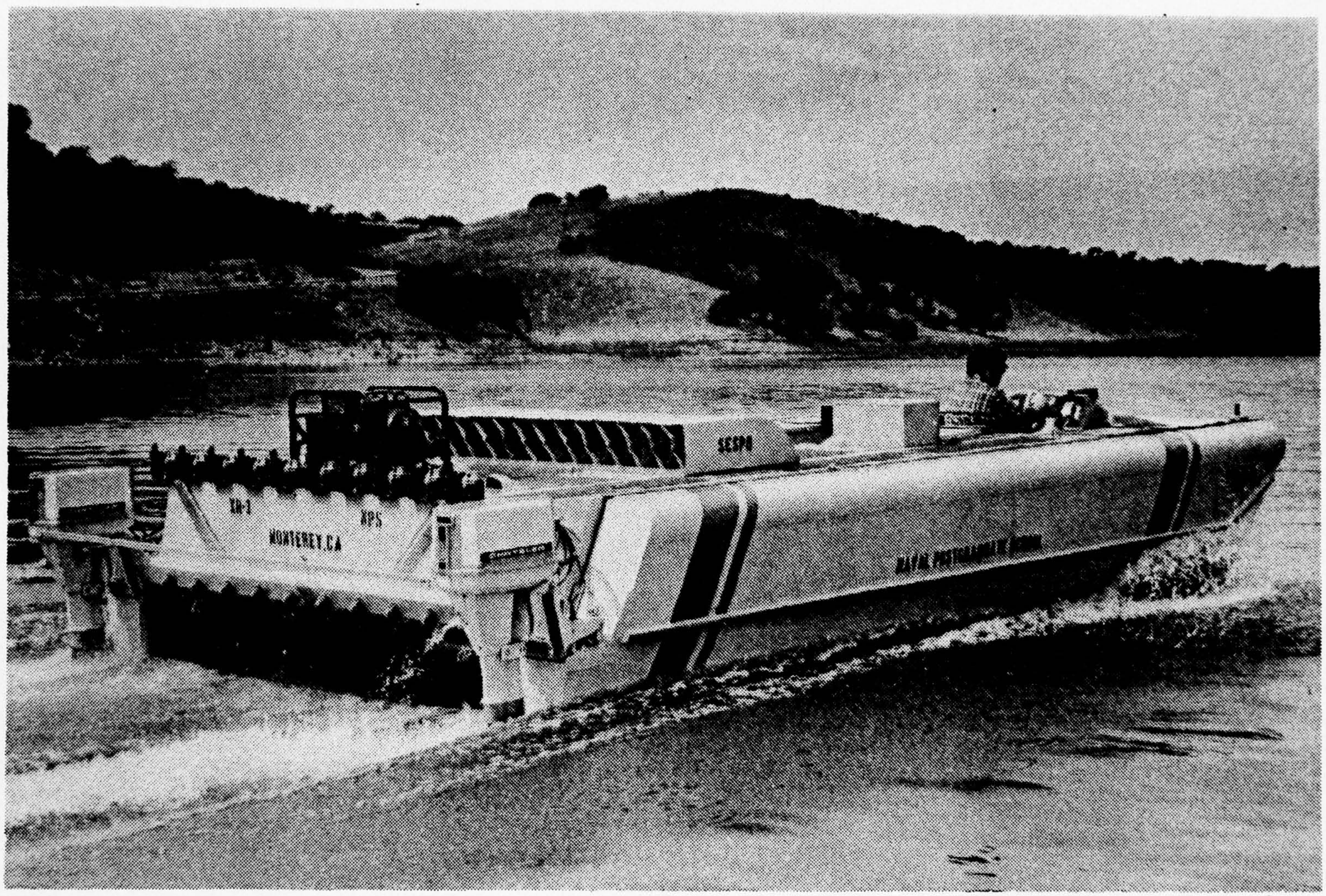

Figure 8. XR-3 POST HUMP - STERN VIEW

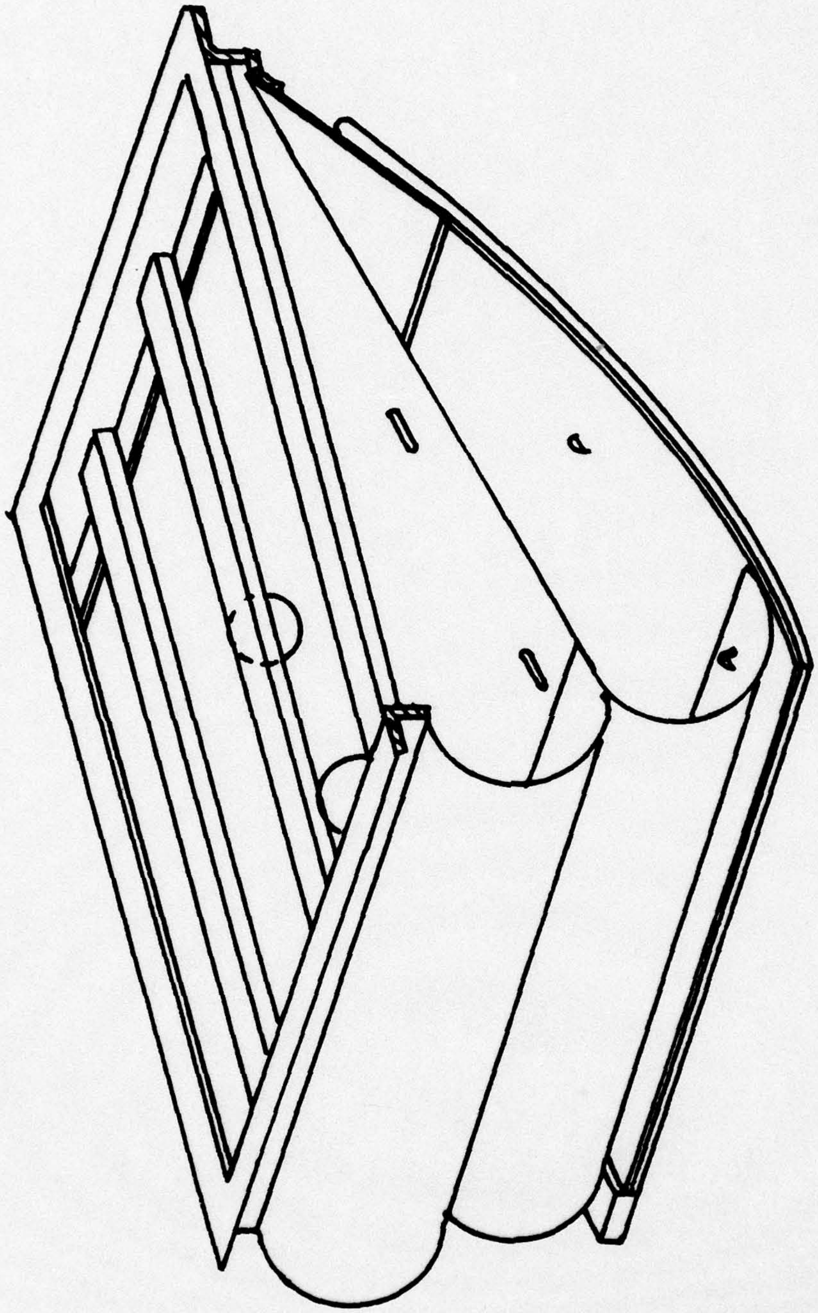

Figure 9. BOW SEAL SECTION

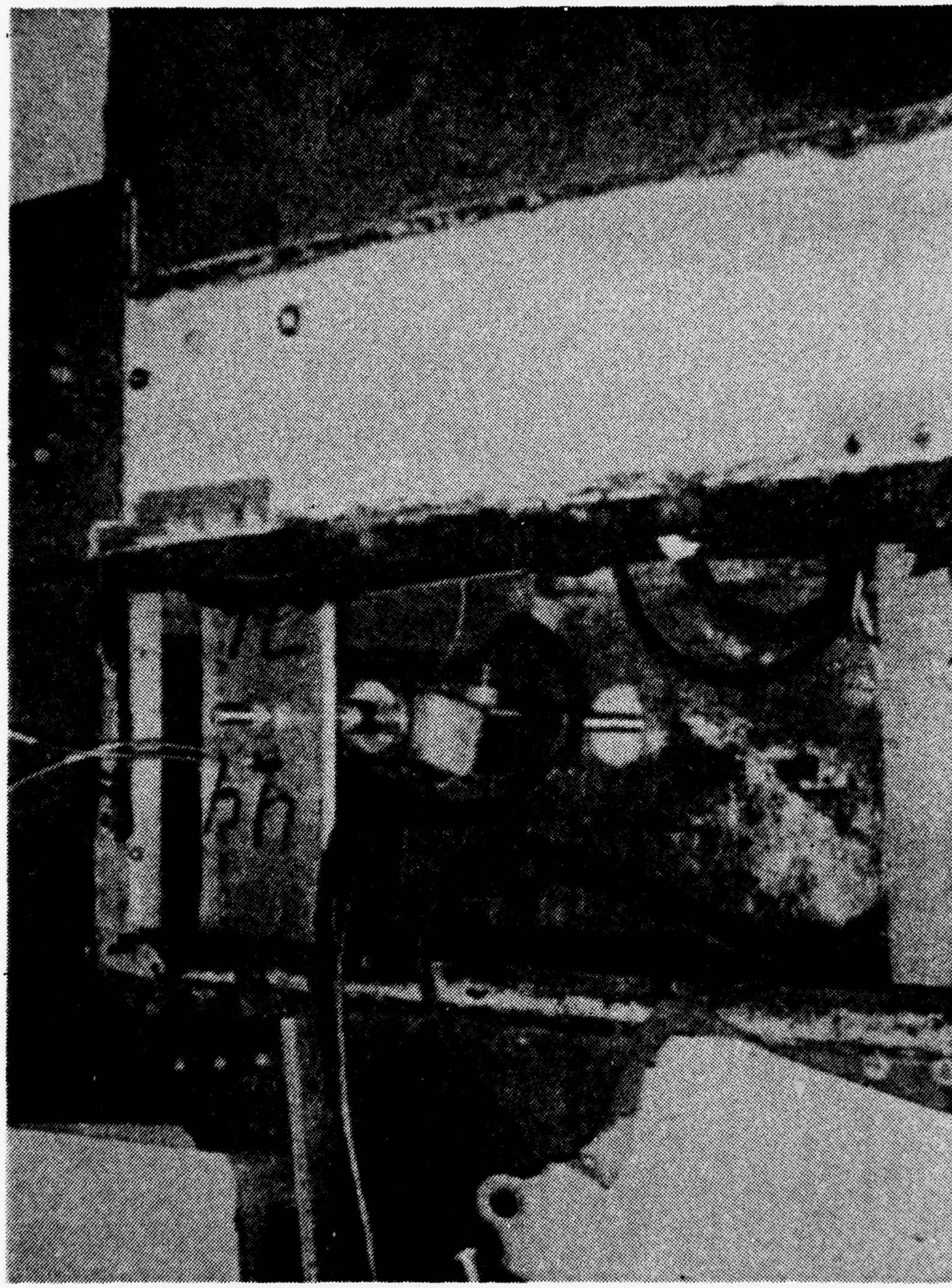

Figure 10. LIFT LOAD CELL - INSTALLED

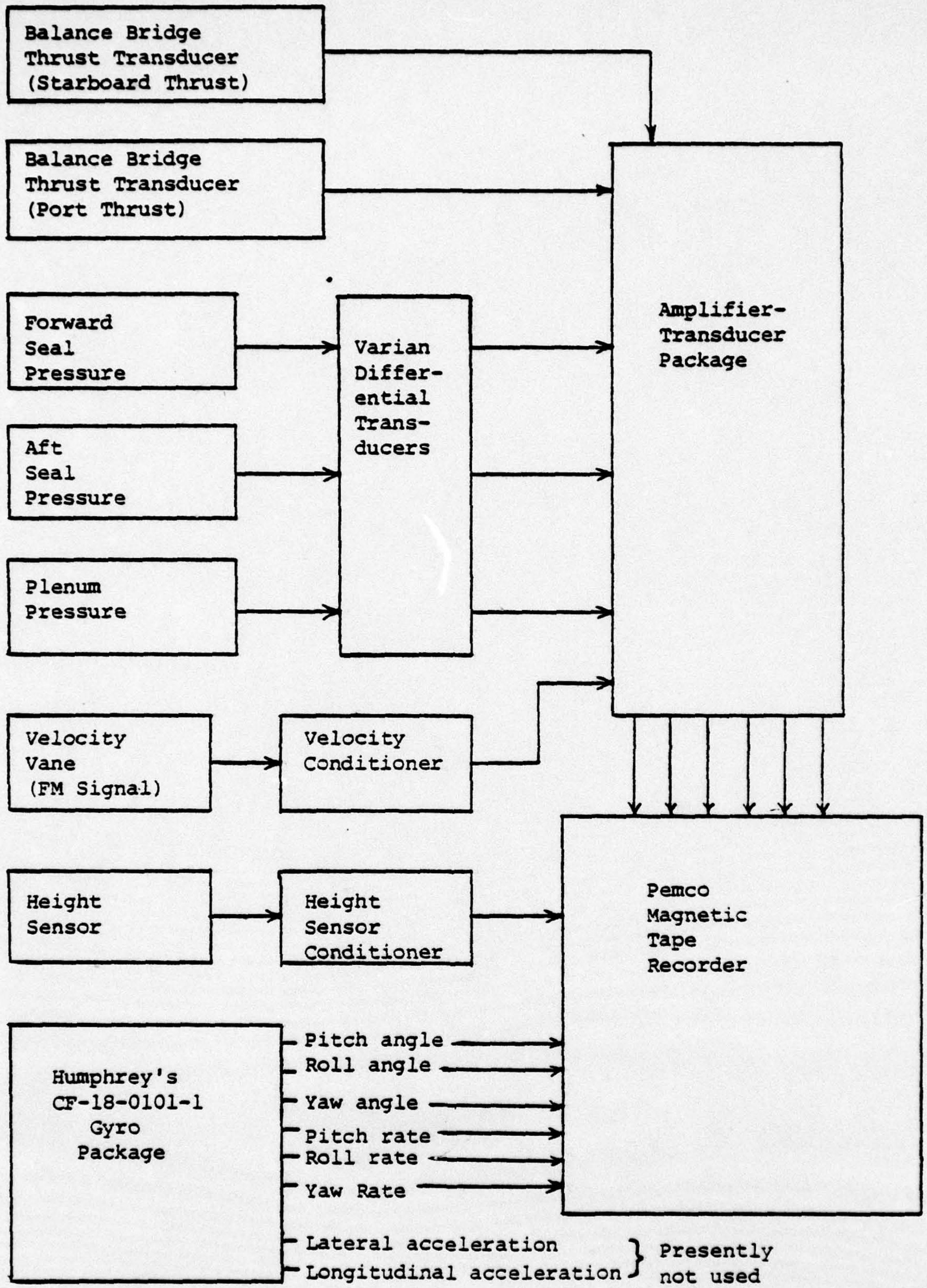

Figure 11. DATA ACQUISITION SYSTEM

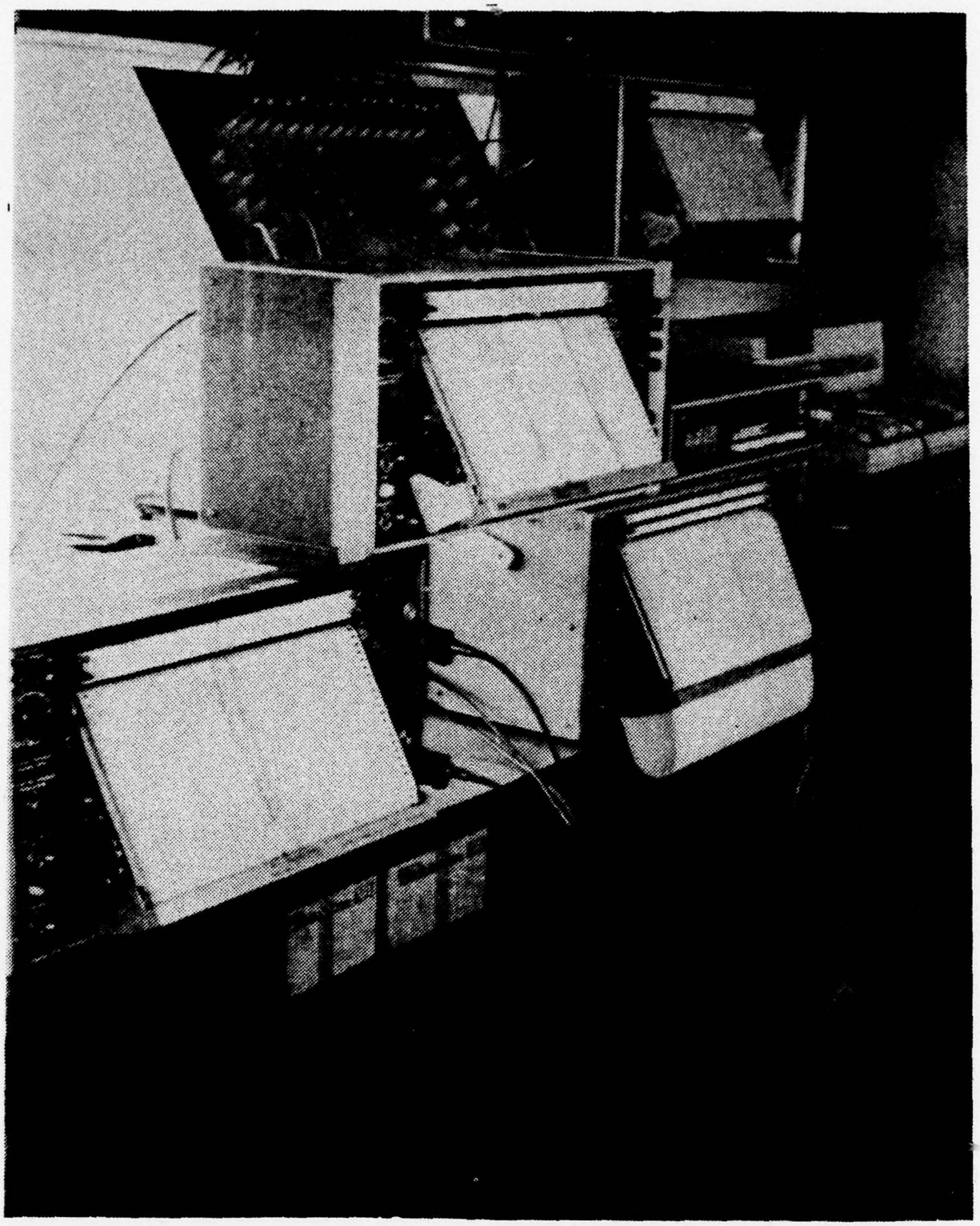

Figure 12. DATA REDUCTION SYSTEM

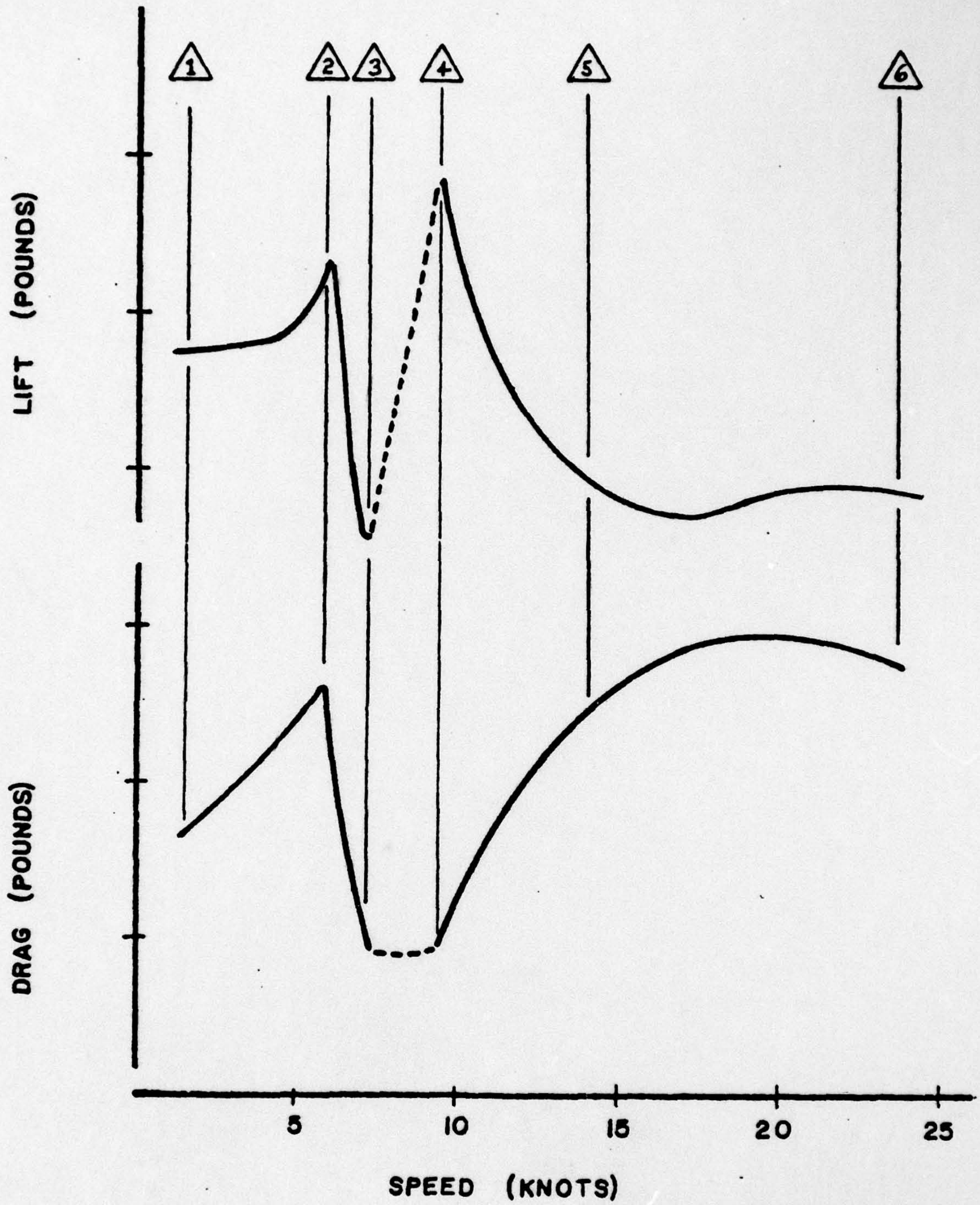

Figure 13. LIFT, DRAG VS. VELOCITY (TYPICAL)

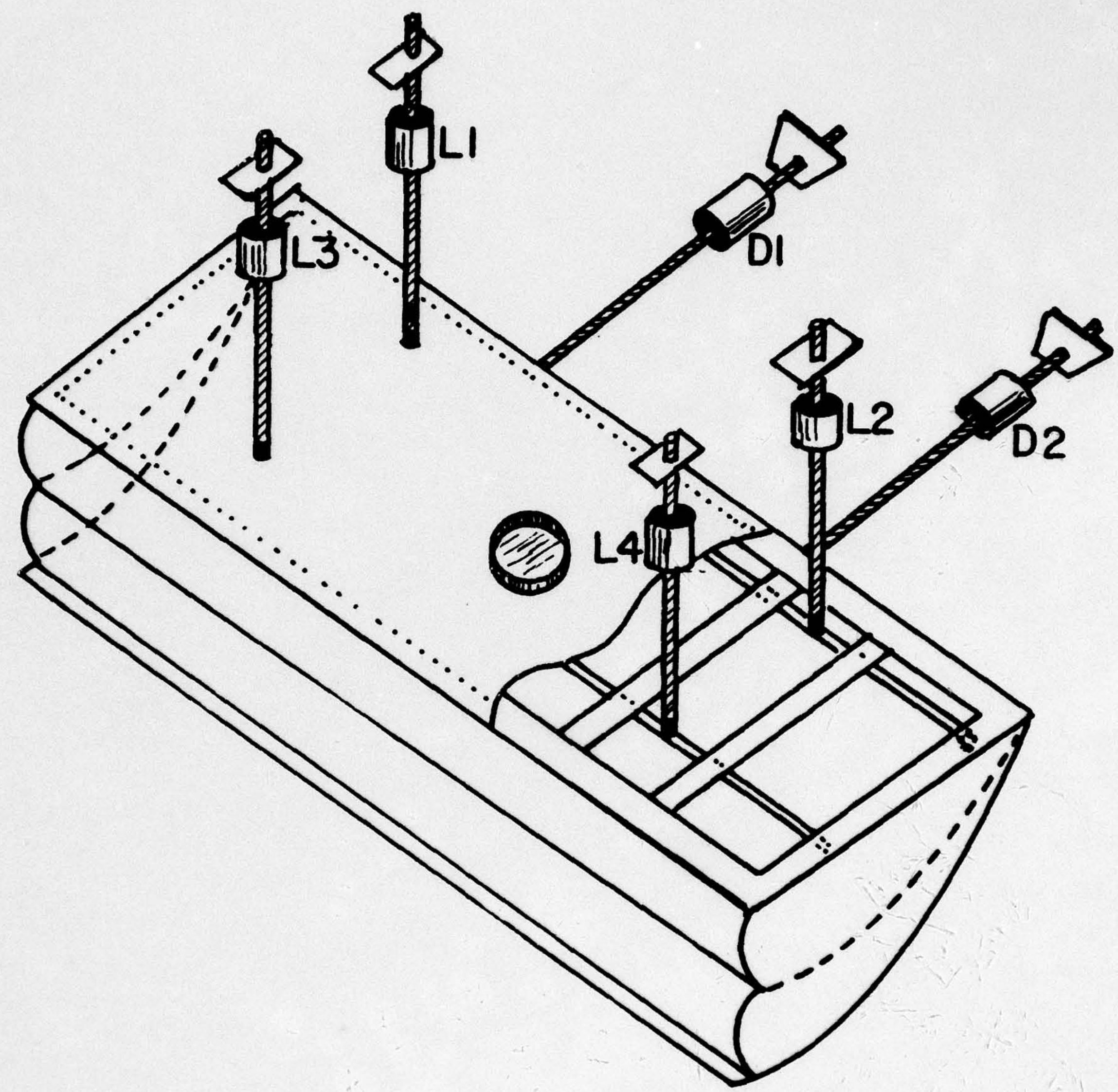

Figure 14. BOW SEAL WITH LIFT AND DRAG CELLS

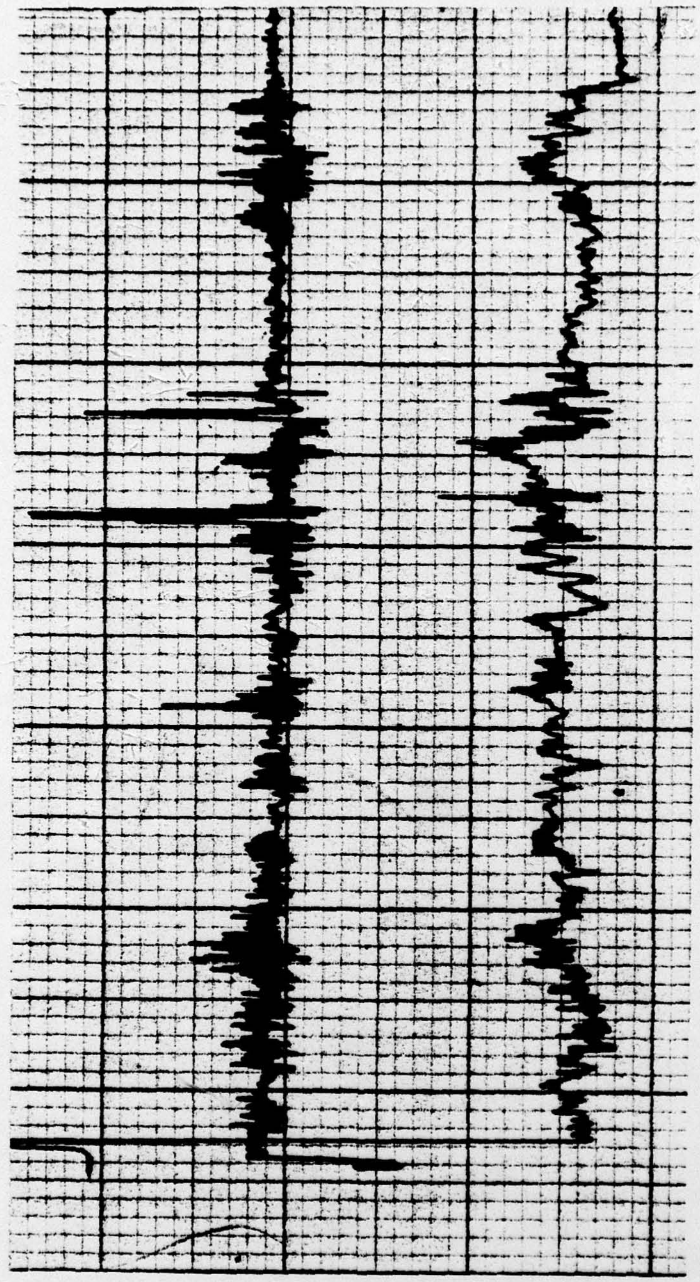

Figure 15. STRIPCHART DATA DISPLAY

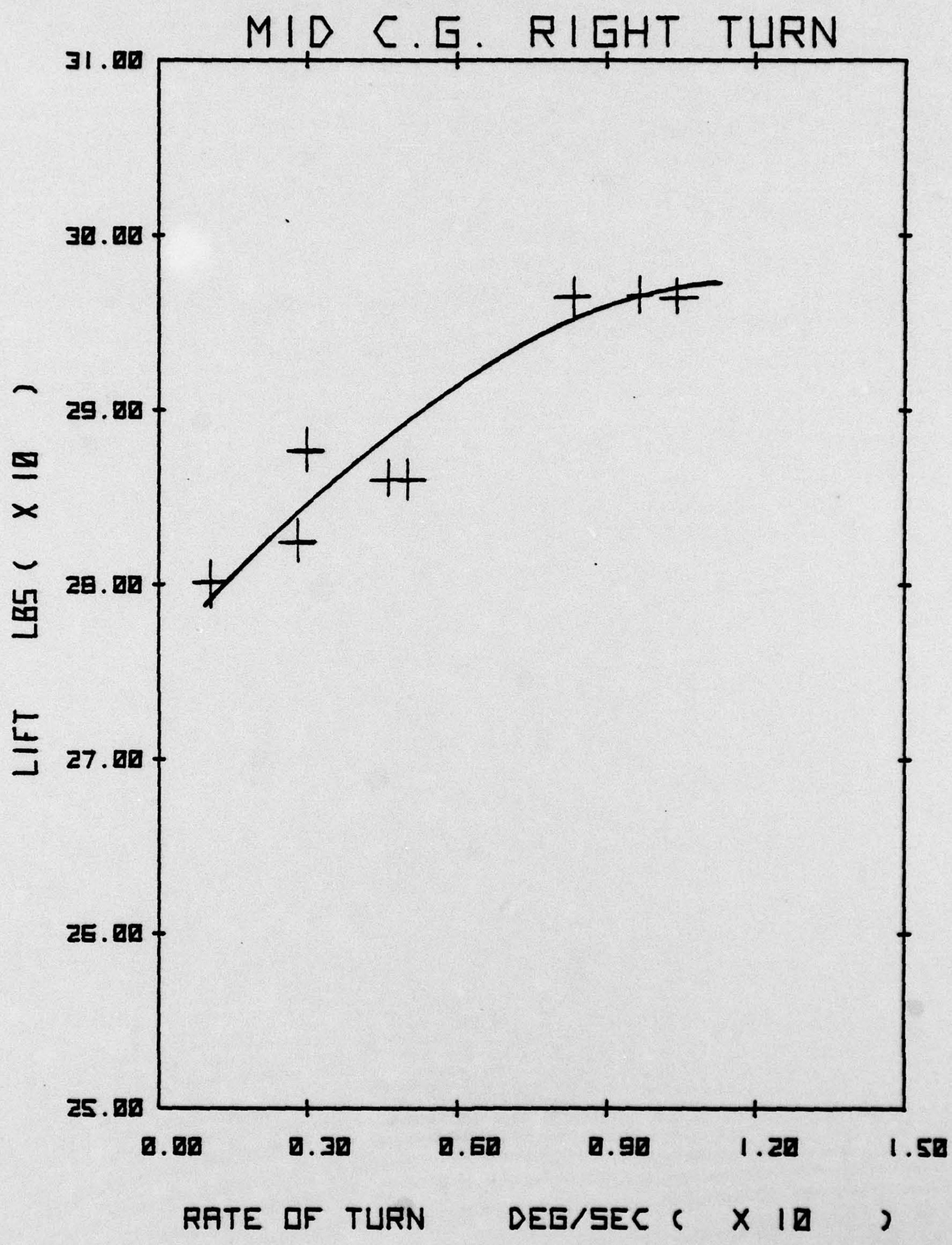

Figure 16. LIFT 2 + Lift 4 VS TURN RATE

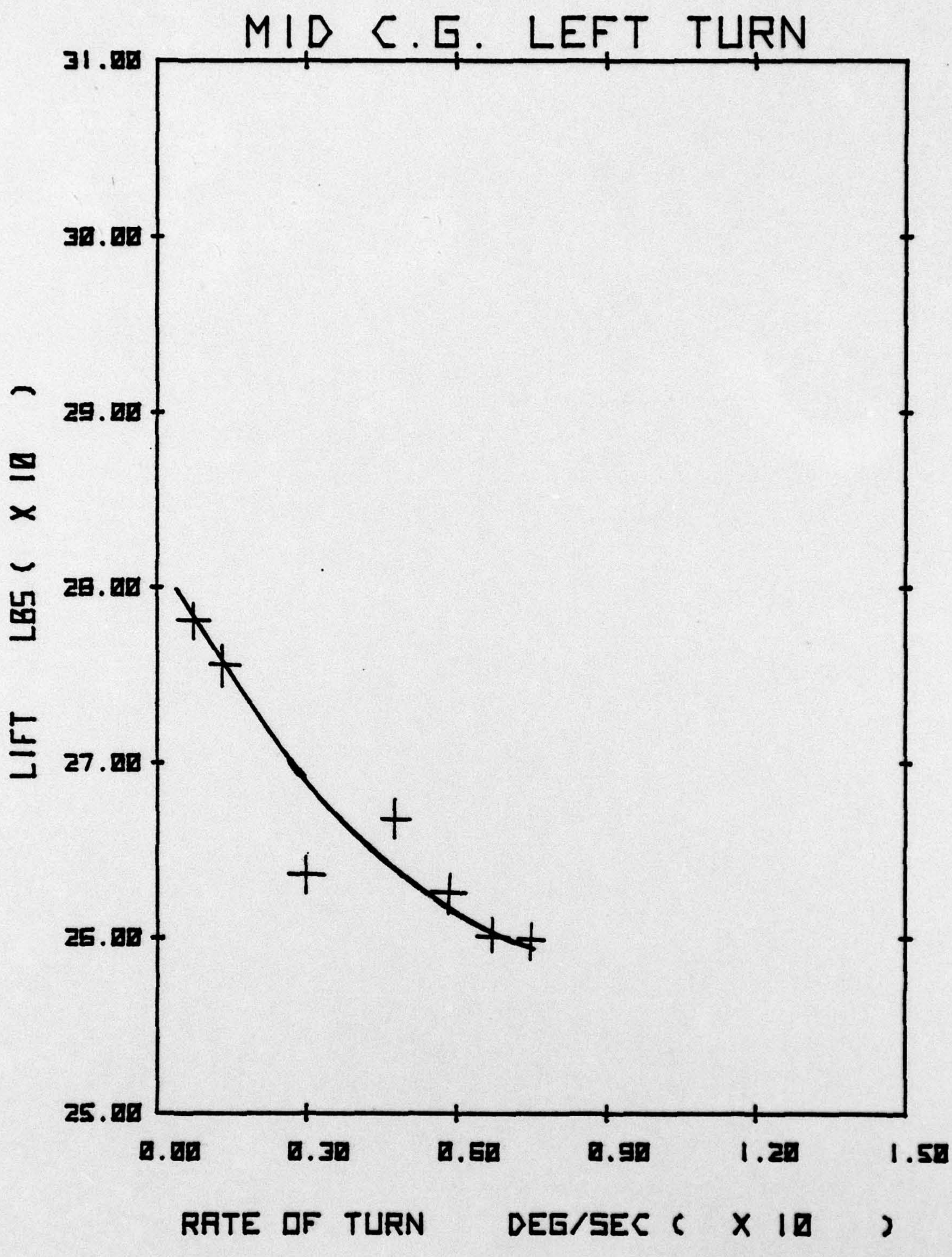

Figure 17. LIFT 2 + LIFT 4 VS. TURN RATE

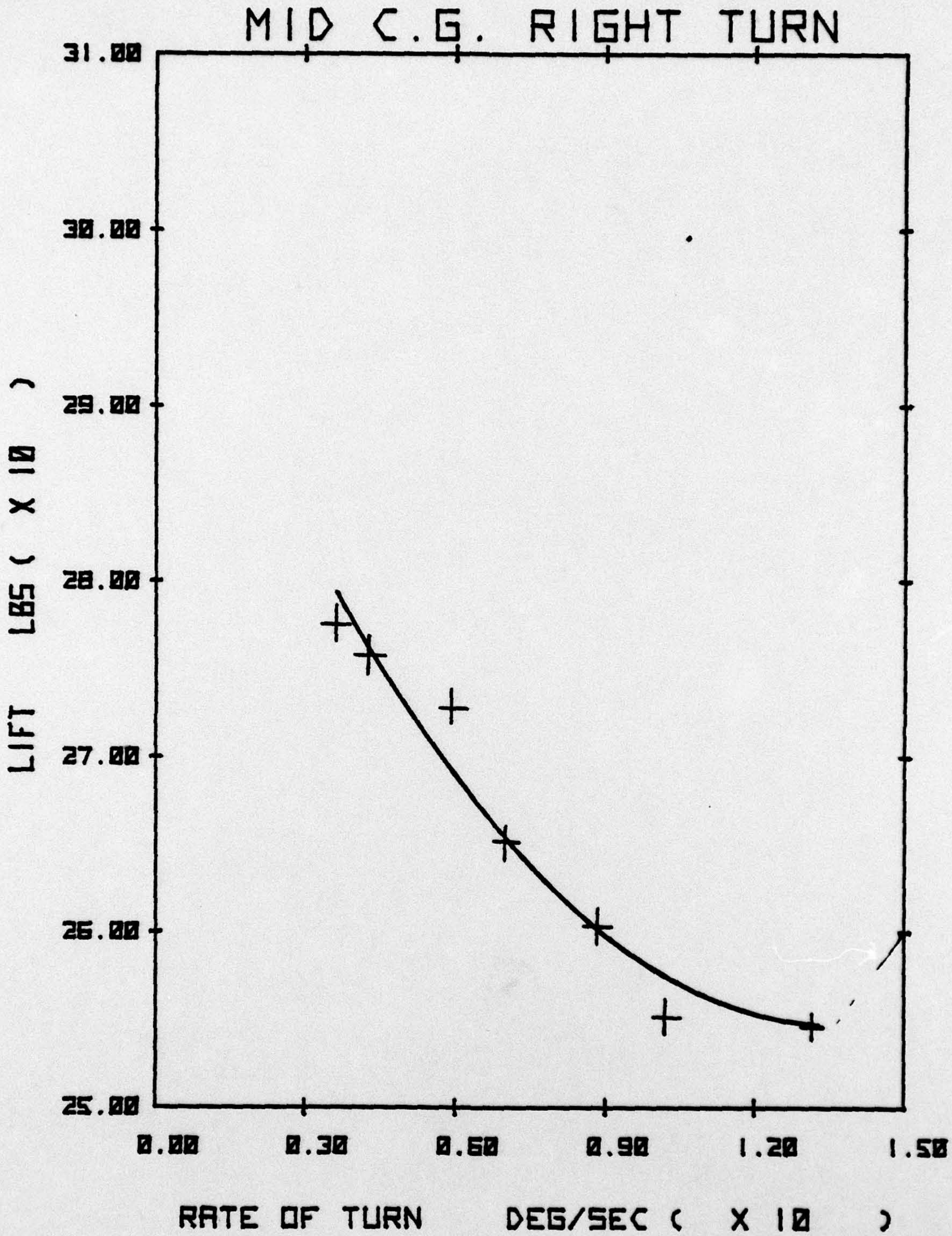

Figure 18. LIFT 1 + LIFT 3 VS. TURN RATE

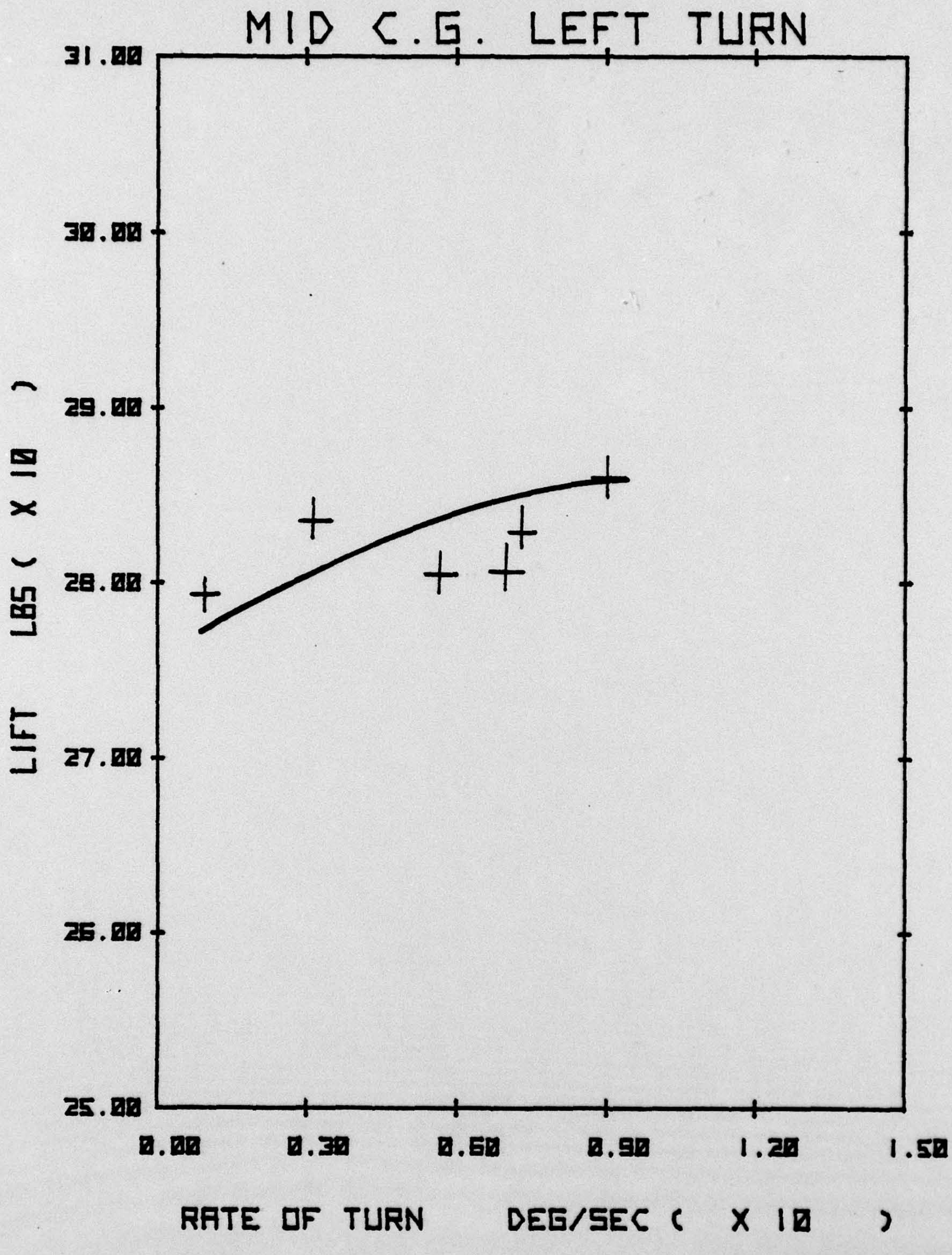

Figure 19. LIFT 1 + LIFT 3 VS. TURN RATE

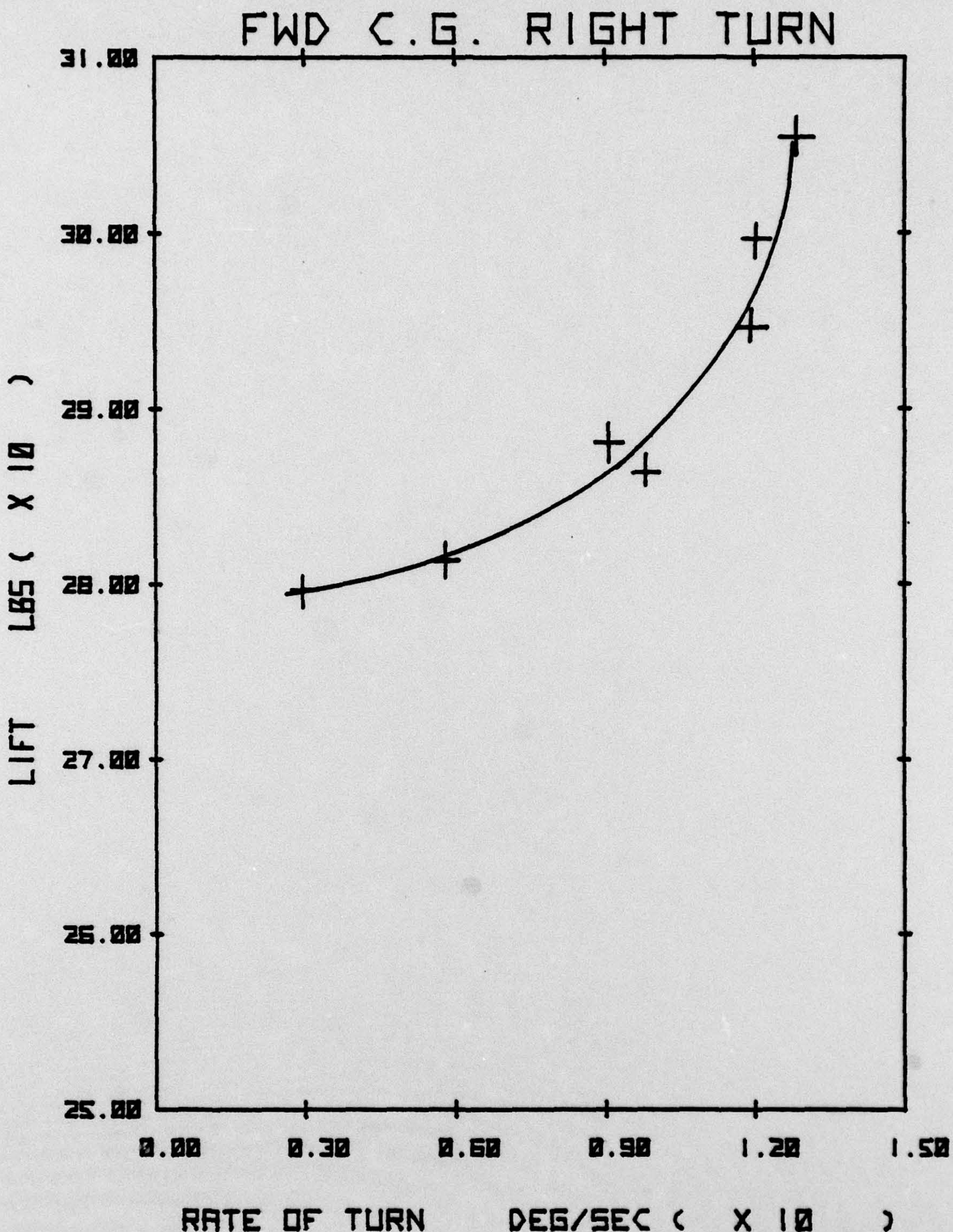

Figure 20. LIFT 2 + LIFT 4 VS. TURN RATE

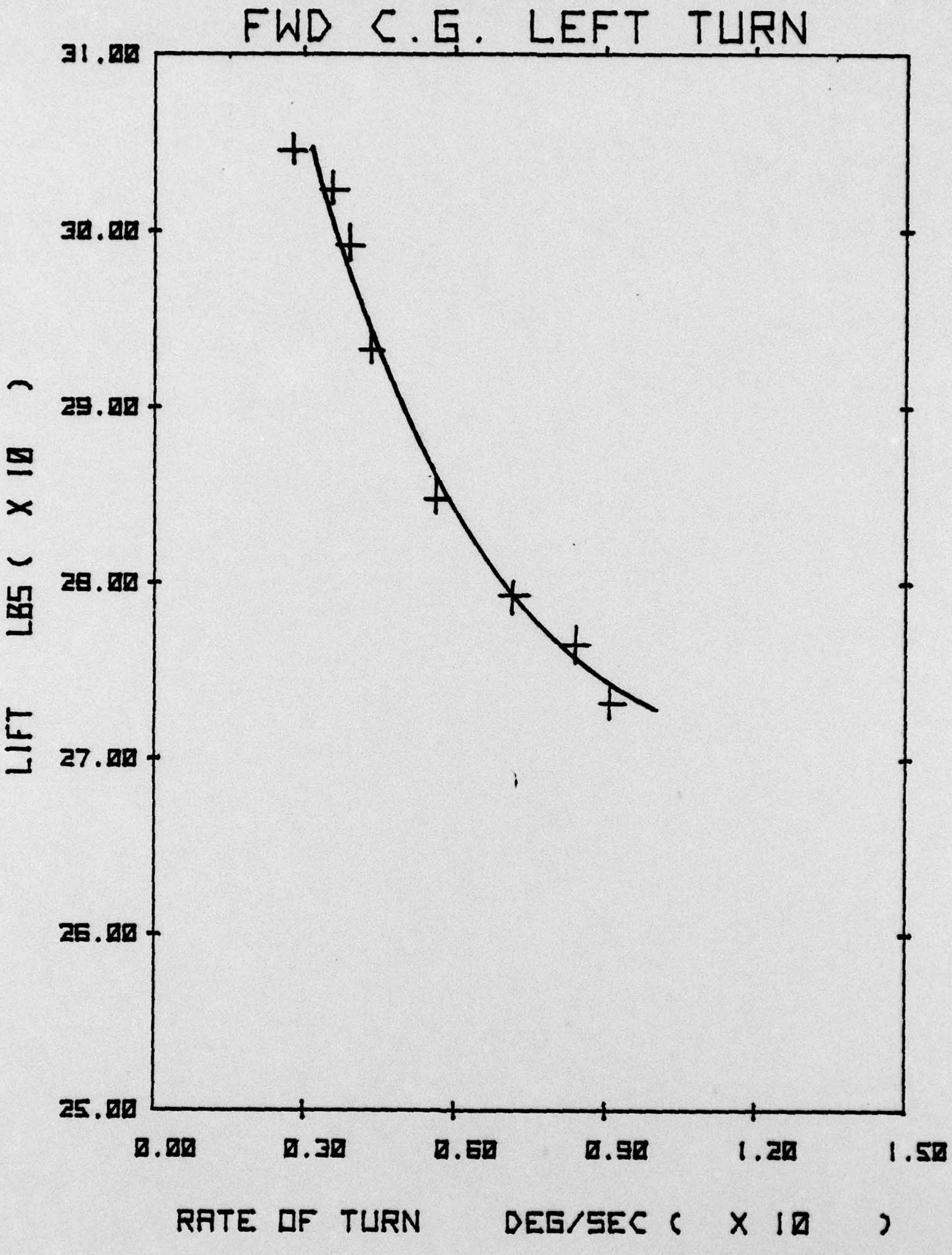

Figure 21. LIFT 2 + LIFT 4 VS. TURN RATE

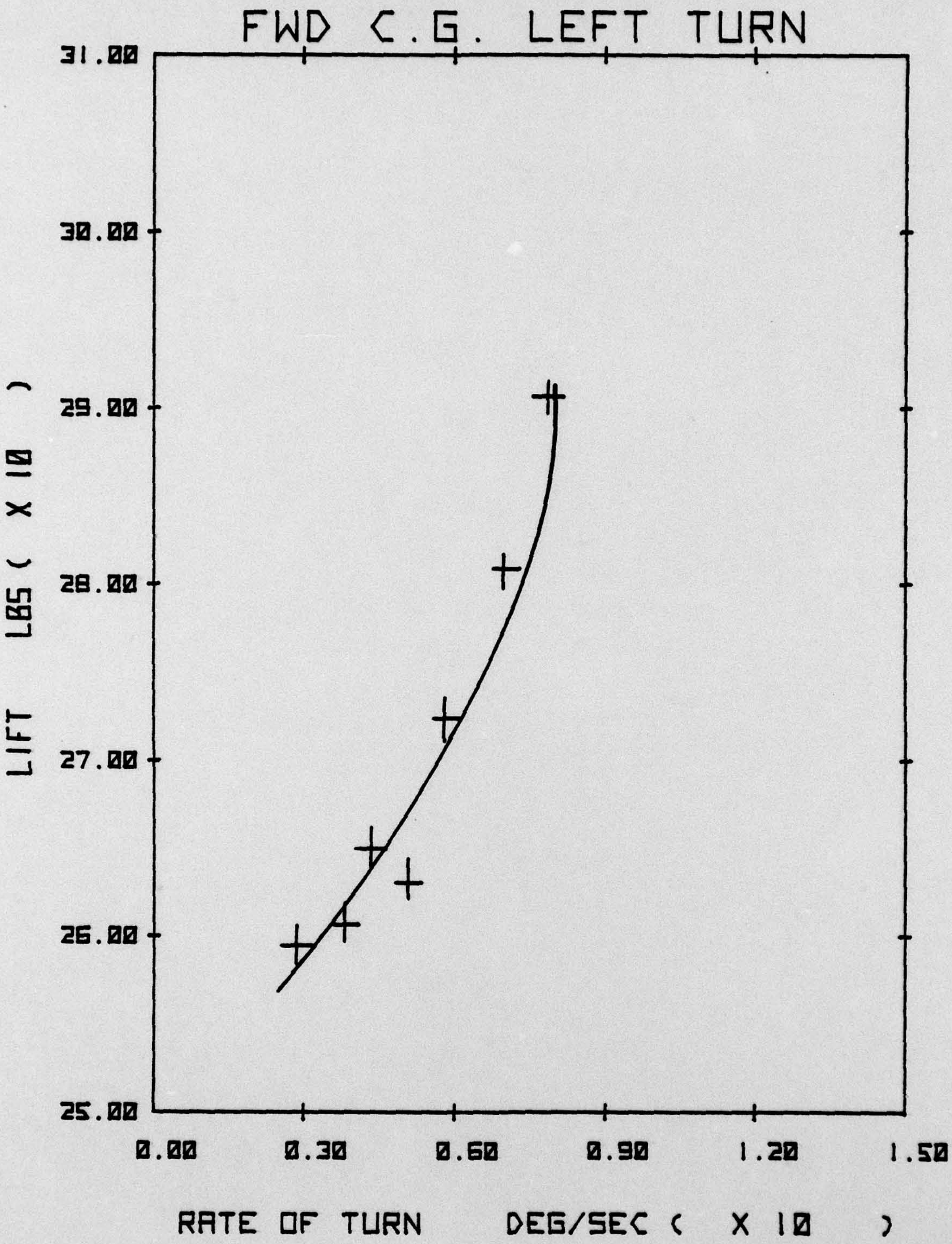

Figure 22. LIFT 1 + LIFT 3 VS. TURN RATE

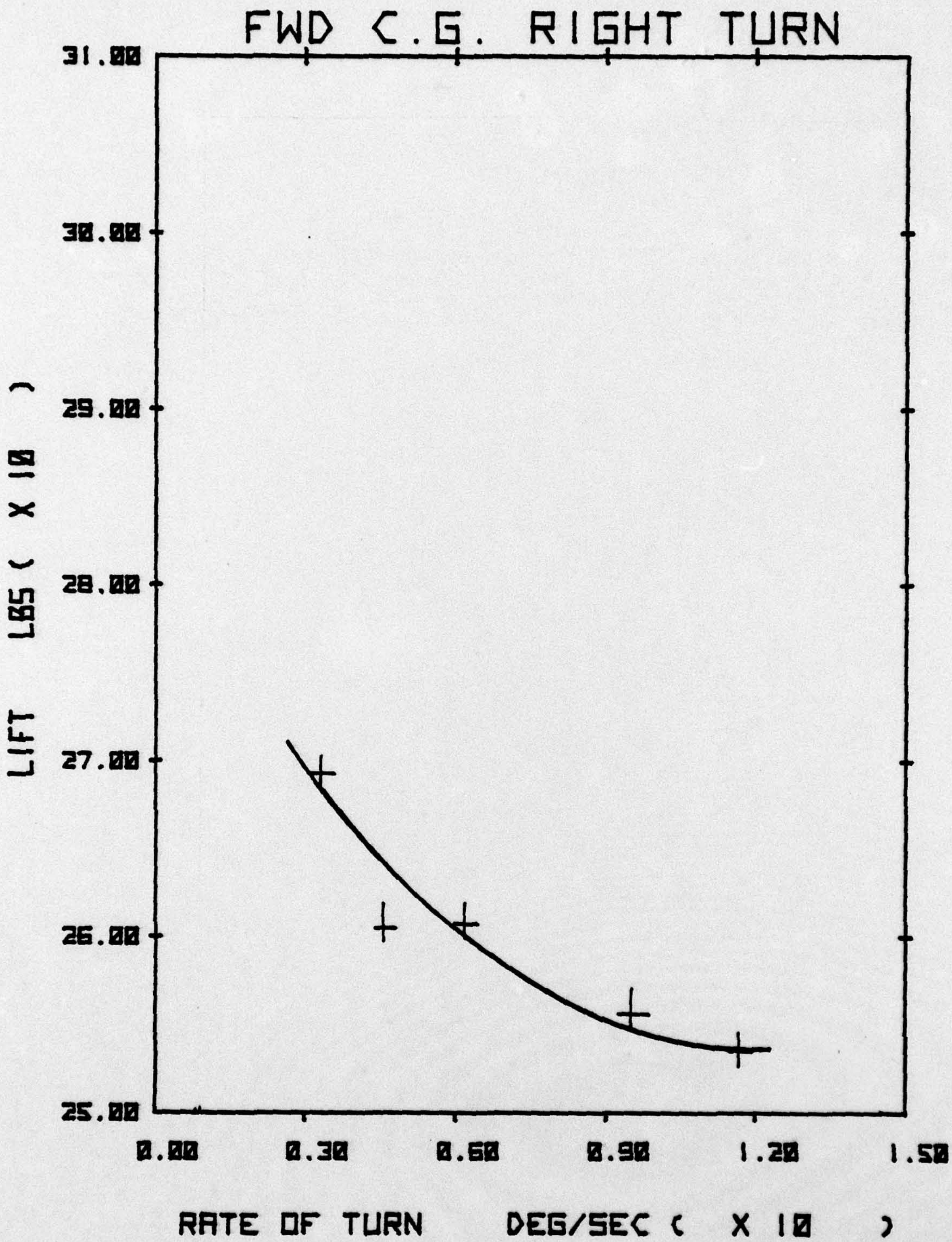

Figure 23. LIFT 1 + LIFT 3 VS. TURN RATE

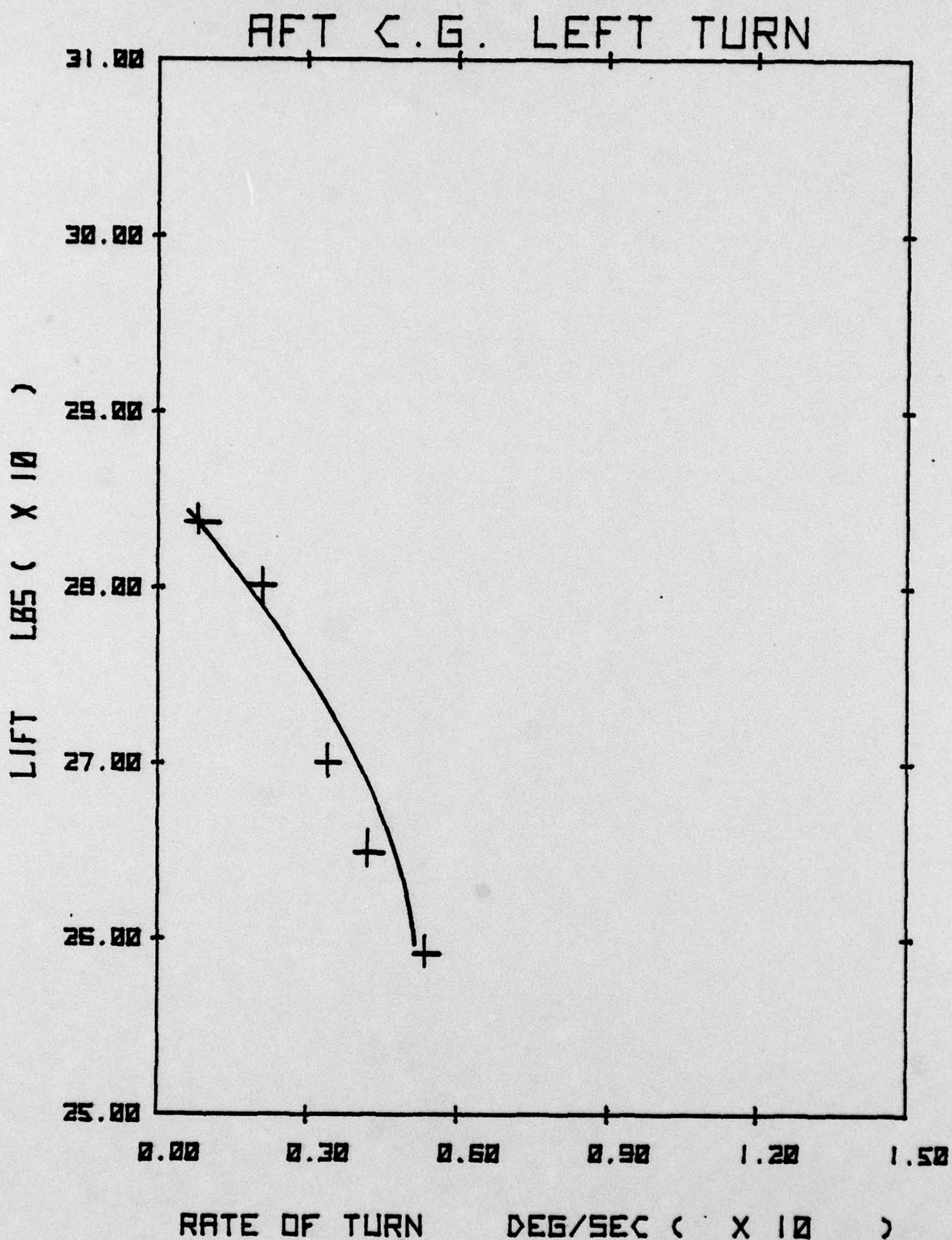

Figure 24. LIFT 2 + LIFT 4 VS. TURN RATE

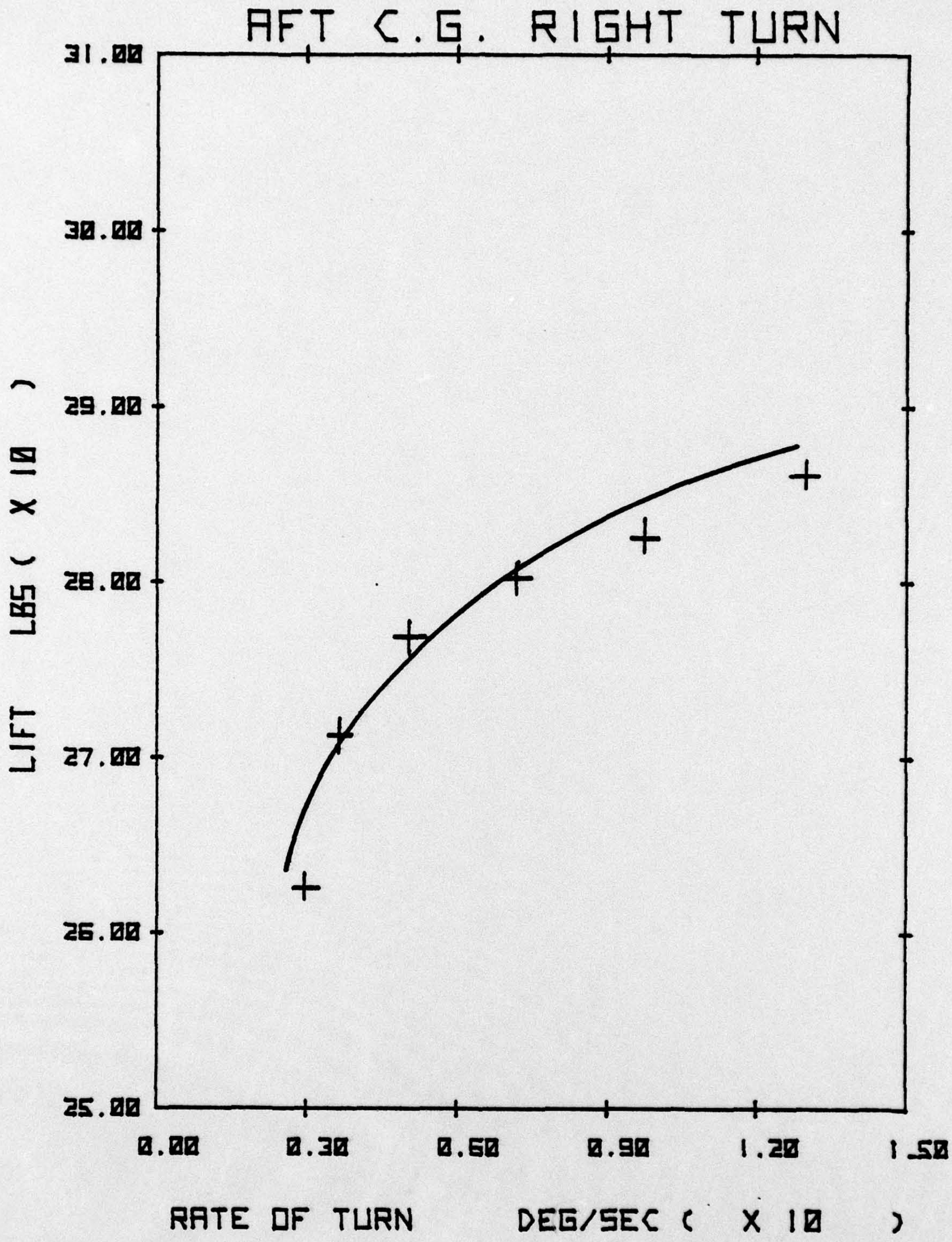

Figure 25, LIFT 2 + LIFT 4 VS. TURN RATE

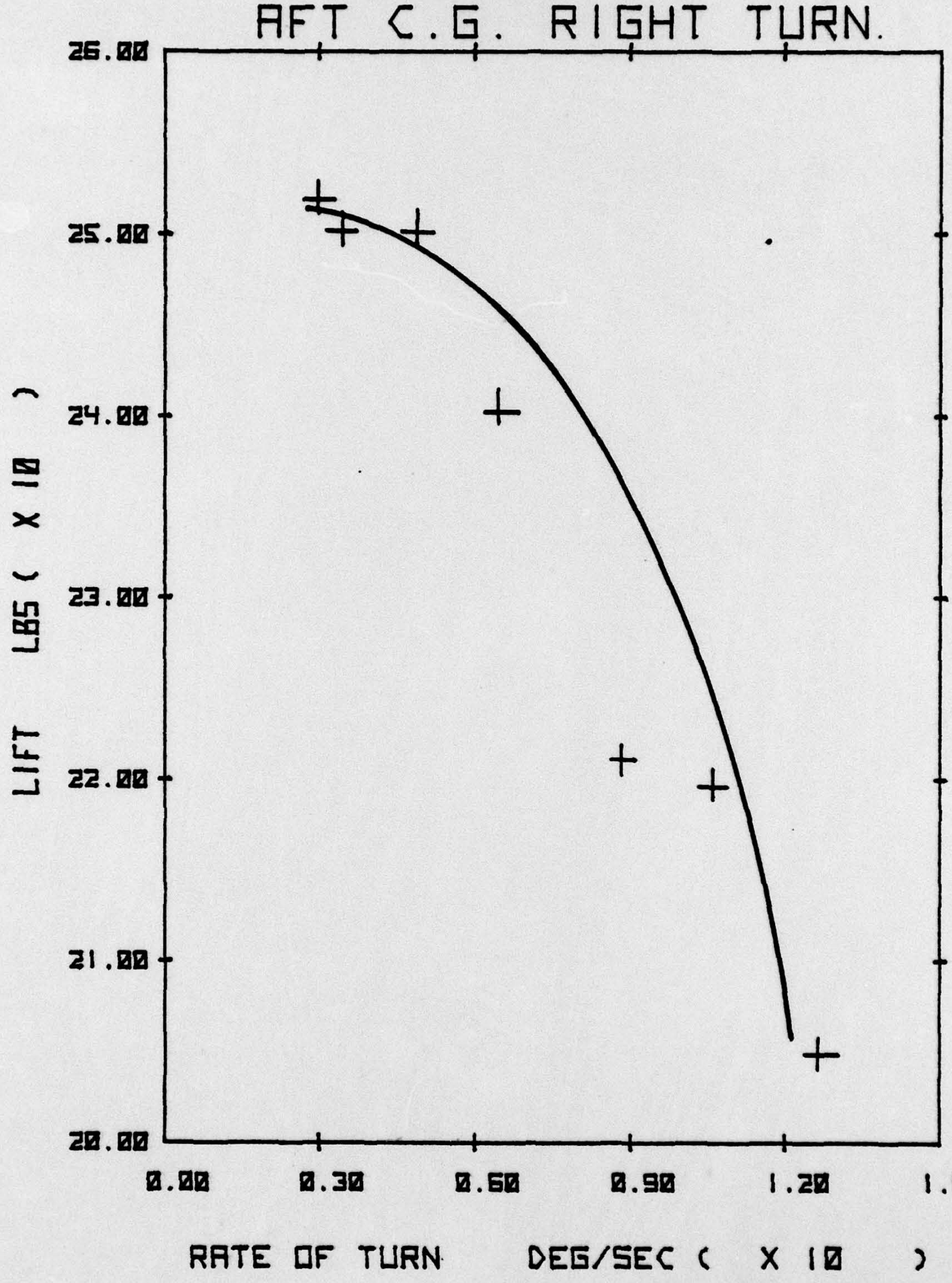

Figure 26. LIFT 1 + LIFT 3 VS. TURN RATE

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